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# COMPARATIVE HEAVY METAL UPTAKE BY SOIL-DWELLING INVERTEBRATES AND THE BIOASSAY EARTHWORM *EISENIA FOETIDA*



Final technical report

by

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The use of invertebrates as indicators of soil pollution has been approached from two directions: either as a predictive laboratory test or as an indicator of field conditions. Under the present contract, the two approaches were compared by measuring concentrations of Zn, Cu, Ni, Cd, Cr, and Pb in soil macro-invertebrates (including native earthworms) collected at field sites and by conducting laboratory uptake studies using the earthworm Eisenia foetida exposed to dredged material and soil from the field sites (earthworm bioassay procedure).

Three upland dredged material disposal sites on which ecosystems had developed to a greater or lesser degree and a reference area of low metal contamination were studied. These were: Times Beach Confined Disposal Facility (CDF), Buffalo, NY, Black Rock Harbour CDF, Bridgeport, CT, and Ottawa Mine Spoil Reclamation Site, Ottawa, IL. The reference area was at Grand Island, Buffalo, NY. At each of the four sites measurements were made of heavy metal concentrations in dredged material/soil, soil-dwelling macro-invertebrates (collected


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by pitfall trapping) and native earthworms (collected by formalin vermifuge). Metal concentrations in earthworms exposed to substrates from each of the sites for 28 days under laboratory conditions were also measured.

Concentrations measured in invertebrates from the field sites also provided information on target organisms for metal uptake at the sites. The spiders (Araneida) and the detritivorous groups: millipedes (Diplopoda), woodlice (Isopoda), and earthworms (Oligochaeta) had the greatest metal concentrations. Earthworms contained the greatest Zn concentrations, Cu concentrations were greater in the Diplopoda, and Cd concentrations similar in range between earthworms and Isopoda. Pb concentrations were within a similar range in earthworms and invertebrates in the pitfall traps. Results suggest that earthworms colonizing the field sites do provide a good indication of the "worst case" of metal uptake by the soil-dwelling invertebrates.

Results of the laboratory uptake studies using E. foetida generally refected the trends observed in metal concentrations measured in invertebrates naturally colonizing the Times Beach CDF, Black Rock CDF, and Grand Island reference site and in most cases provided a valid indication of the relative hazard posed by the elements Zn, Cu, Cd, and Pb. However, metal concentrations in invertebrates at the Ottawa mine spoil reclamation site did not correspond with those expected from the laboratory uptake study.

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## Abstract

The use of invertebrates as indicators of soil pollution has been approached from two directions: either as a predictive laboratory test or as an indicator of field conditions. Under the present contract, the two approaches were compared by measuring concentrations of Zn, Cu, Ni, Cd, Cr and Pb in soil macro-invertebrates (including native earthworms) collected at field sites and by conducting laboratory uptake studies using the earthworm *Eisenia foetida* exposed to dredged material and soil from the field sites.

Three upland dredged material disposal sites on which ecosystems had developed to a greater or lesser degree and a reference area of low metal contamination were studied. These were: Times Beach Confined Disposal Facility (CDF), Buffalo, NY, Black Rock Harbor CDF, Bridgeport, CT and Ottawa Mine Spoil Reclamation Site, Ottawa, IL. The reference area was at Grand Island, Buffalo, NY. At each of the four sites measurements were made of heavy metal concentrations in dredged material/soil, soil-dwelling macro-invertebrates (collected by pitfall trapping) and native earthworms (collected by formalin vermifuge). Metal concentrations in earthworms exposed to substrates from each of the sites for 28 days under laboratory conditions were also measured (earthworm bioassay procedure).

Concentrations measured in invertebrates from the field sites also provided information on target organisms for metal uptake at the sites. The spiders (Araneida) and the detritivorous groups: millipedes (Diplopoda), woodlice (Isopoda) and earthworms (Oligochaeta) had the greatest metal concentrations. Earthworms contained the greatest Zn concentrations, Cu concentrations were greater in the Diplopoda and Cd concentrations similar between earthworms and Isopoda. Pb concentrations were within a similar range in earthworms and invertebrates in the pitfall traps. Results suggest that earthworms colonizing the field sites do provide a good indication of the 'worst case' of metal uptake by the soil-dwelling invertebrates.

Results of the laboratory uptake studies using *E. foetida* generally reflected the trends observed in metal concentrations measured in invertebrates naturally colonizing the Times Beach CDF, Black Rock CDF and Grand Island reference site and in most cases provided a valid indication of the relative hazard posed by the elements Zn, Cu, Cd and Pb. However, metal concentrations in invertebrates at the Ottawa mine spoil reclamation site did not correspond with the pattern expected from the laboratory uptake study.

1. **INTRODUCTION**

The United States Army Corps of Engineers (USACE) is responsible for the maintenance of navigable channels through the waterways of the United States. As a result, each year they are required to dispose of large quantities of dredged material which may be contaminated as a result of industrial and sewage effluent and run off from agricultural land and mining operations. The choice of areas onto which the dredged material is disposed and their subsequent management depends upon the mobility of contaminants in the material. To assess contaminant mobility and bioavailability, the USACE, Environmental Laboratory at Waterways Experiment Station (WES), Vicksburg, Mississippi, has laboratory procedures, measuring plant and animal uptake from dredged material, to indicate the potential hazard at dredged material disposal facilities (Folsom et al., 1981, Simmers et al., 1986, Lee et al., 1984). The use of earthworms for this purpose has been suggested by the USACE in relation to the environmental effects of dredging (Marquenie & Simmers, 1984, Simmers et al., 1986) and by the US Environmental Protection Agency (EPA) in relation to the assessment of hazardous waste disposal sites (Callahan et al., 1985, Miller et al., 1985).

At WES, a laboratory procedure measuring uptake of contaminants from dredged material under oxidized conditions (to simulate upland disposal) has used the earthworm *Eisenia foetida* (Rhett et al., 1984). This procedure was modified from a test developed at Rothamsted Experimental Station (Harpenden, Herts.) for use by the European Economic Community (EEC) in eco-toxicological testing of agro- and industrial chemicals entering the market (CEC Directive 79/81, 1984). In the field, earthworms have been collected and their tissues analyzed and found to provide an indication of metal concentrations in the soils (van Rhee, 1975, 1977, Helmke et al., 1979, Curry & Cotton, 1980, Beyer et al., 1982, Martin & Coughtrey, 1982). Other organisms, naturally colonizing contaminated sites, for example woodlice (Weiser et al., 1976, Coughtrey et al., 1977, Williamson, 1979), snails (Meinckee & Schaller, 1974) and surface dwelling invertebrates in general (Wade et al., 1980) have also been used to indicate the presence of bioavailable contaminants.

To investigate the ability of the WES laboratory test procedure to assess relative hazard posed by the elements: Zn, Cu, Cd and Pb in dredged material at upland confined disposal facilities (CDF), results of laboratory earthworm uptake studies were compared with measurements of these elements in invertebrates naturally colonizing CDFs containing contaminated dredged material.

The research objectives may be summarized as follows:-

(1) To compare heavy metal uptake by the earthworm *E. foetida* exposed to dredged material under laboratory conditions with metal concentrations measured in native earthworms and soil-dwelling invertebrates naturally colonizing dredged material disposal facilities. To thereby assess the validity of using *E. foetida* to indicate contaminant bio-availability in dredged materials at upland dredged material disposal facilities.

(2) To identify 'target organisms' among soil-dwelling invertebrates in terms of abundance at the CDFs and heavy metal uptake into the tissues and to assess their future significance as indicator species/groups/niches in the study of potential hazard posed by dredged material disposal facilities.

To achieve these objectives three CDFs and a reference site were selected for study. Elevated concentrations of metals have been recorded in dredged material from the Times Beach CDF (Marquenie et al. 1987), Black Rock Harbor CDF (Rogerson et al., 1985) and Ottawa mine spoil reclamation site (Rhett and Richards, 1986, Rhett et al., 1987). Preliminary assessments of the mobility of contaminants indicated a potential for movement into plant and animal tissues from the Times Beach dredged material (Folsom, 1981, Simmers & Rhett, 1983), Black Rock Harbor dredged material (Yevich et al., 1987) and Ottawa mine spoil dredged material (Rhett & Richards, 1986, Rhett et al., 1987). From each of the CDFs and the reference site dredged material/soil were collected and returned to the laboratory to conduct earthworm uptake studies. Each of the sites were naturally colonized to some degree by vegetation and associated fauna and samples of invertebrates, including native earthworms, were collected and returned to the laboratory for identification and metal analysis.

## 2. MATERIALS AND METHODS.

### 2.1 SITE SELECTION AND DESCRIPTION.

Three upland, dredged material confined disposal facilities (CDF) and one reference site, known to contain low concentrations of heavy metals, were selected.

2.1.1 Times Beach CDF: Times Beach CDF, Buffalo NY was created by the Buffalo District Army Corps of Engineers to contain sediment dredged from the Buffalo Harbor, known to be contaminated by effluent from industries along the Buffalo River. Disposal of dredged material ceased at Times Beach in 1976 and the upper layer of dredged material has consolidated to produce a soil-like layer supporting the growth of vegetation. Beneath the upper consolidated layer, the unconsolidated dredged material remains close to its original form. Depth of the consolidated soil-like layer depends upon its elevation relative to the water table. A woodland ecosystem has developed in the upland area of the CDF (Figure 1) and three distinct vegetation zones (A, B, C) were defined (see reports by Wilhelm in Stafford et al., 1987):

Vegetation zone A is the highest and driest of the zones. It is wooded, almost entirely by Populus deltoides (Cottonwood) and dominated beneath by the perennial Solidago altissima (Tall Goldenrod).

Vegetation zone B is, on the whole, 0.6 to 0.9 m lower in elevation than zone A; the canopy is also dominated by Cottonwood, but there is a lower story characterized by Cornus stolonifera (Red Osier Dogwood) and a few Salix spp. (Willows). The ground cover is relatively diverse, dominated by Impatiens capensis (Common Jewel Weed), Lythrum salicaria (Purple Loosestrife) and Goldenrods.

Vegetation zone C is the lowest of the zones in the upland area. It is also characterized by a canopy of Cottonwoods but there is no significant middle shrub story. The ground cover is dominated by Common Jewel Weed.

In association with the colonizing vegetation a diversity of invertebrate fauna and vertebrates, resident and migratory, have been recorded (see reports by Stafford, Bater and Andrle in Stafford et al., 1987).

2.1.2 Grand Island reference site: A woodland ecosystem established on soil derived from river sediments was selected by the Buffalo District Corps of Engineers for comparison with Times Beach CDF. Dominant tree species at Grand Island, Buffalo NY, were Fraxinus pennsylvanica (Pennsylvania Ash), Quercus macrocarpa and Quercus palustris (Oak spp.), and Salix fragilis (Willow). A more complete description of the vegetation at Grand Island is given by Wilhelm in Stafford et al. (1987).

2.1.3 Black Rock Harbor CDF: The Black Rock Harbor CDF, Bridgeport CT, was created under the Field Verification Program (FVP) of the U.S. Army Engineer Waterways Experiment Station (WES) Dredged Material Research Program (DMRP). Dredged material from the harbor was pumped into the CDF in 1981. After some consolidation of the material had occurred, the central area was divided into twenty sub-plots (in 1983) each treated with different combinations of lime, sand, manure and gravel (Figure 2). Grass seed was applied and a sparse cover of grasses have colonized the consolidating sediment at the site. Further details of the construction and development of the site are given elsewhere (Peddicord, 1987).

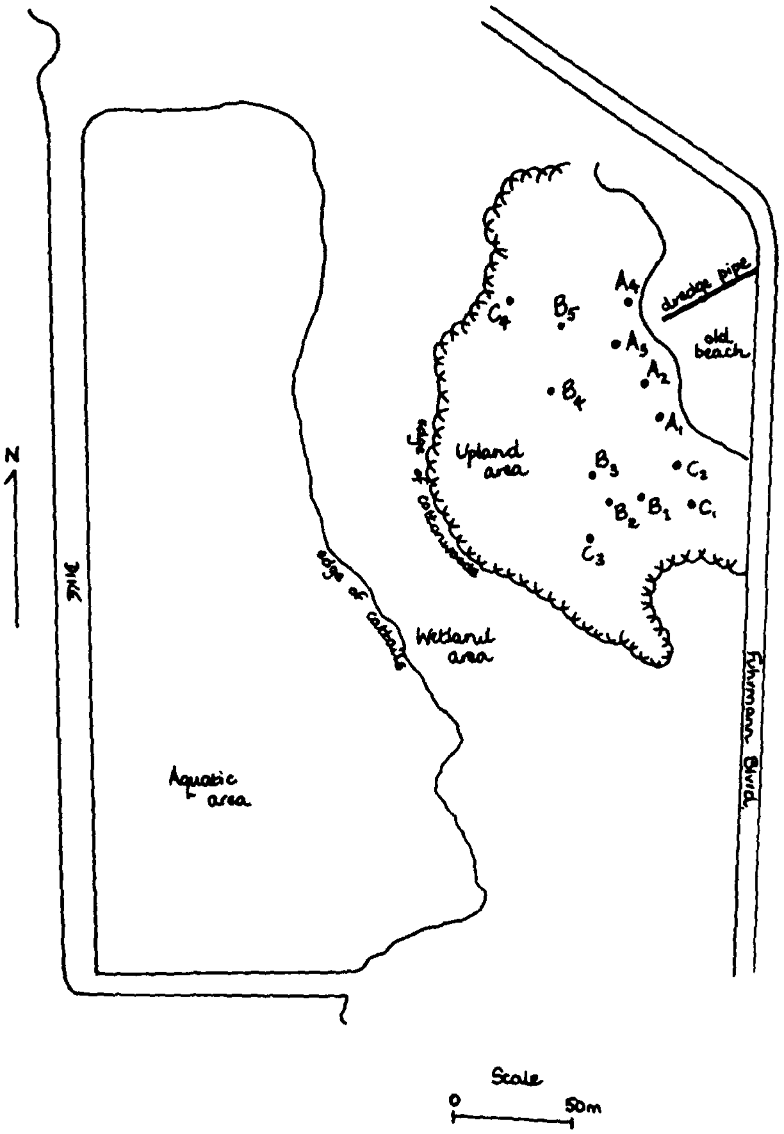


Figure 1: · Times Beach CDF: positions of pitfall traps for collection of invertebrates

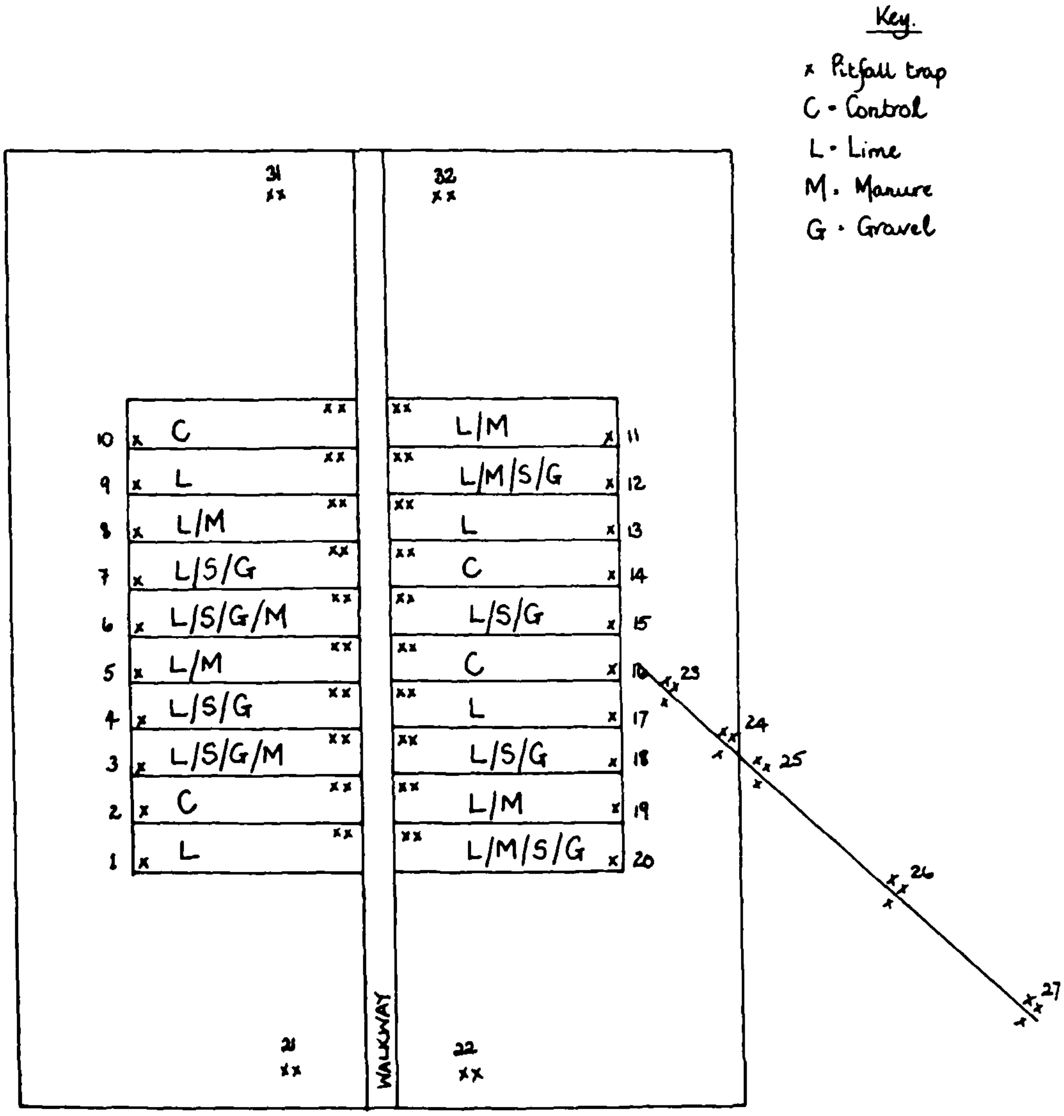


Figure 2: Black Rock Harbor CDF: position of pitfall traps for the collection of invertebrates

2.1.4 Ottawa mine spoil reclamation site: Pilot studies using dredged material for the reclamation of land used for strip mining were initiated in 1978 as a Productive Uses Project (PUP) of the U.S. Army Engineer, Waterways Experiment Station (WES) Dredged Material Research Program (DMRP). Within a 0.5 hectare site at Ottawa IL., pyritic mine spoil was levelled and divided into four plots (Figure 3). Plots were separated from each other by impervious dikes. In plot 1, (the control plot) pyritic mine spoil remained untreated, in plot 2, a meter depth of dewatered dredged material was added and in plots 3 and 4 crushed agricultural limestone (11 metric tons/ha and 17 metric tons/ha, respectively) was mixed with the top 15cm of mine spoil before addition of the dewatered dredged material (1 meter depth). Construction of the site has been described by Perrier et al., (1978). In 1978, all plots were seeded with a mixture of grass species. Development of vegetation at the Ottawa site is described by Simmers et al. (1984). In each plot, five sub-plots were delineated for management of vegetative cover. Sub-plot (a) was mown and the organic matter removed, sub-plot (b) was planted with a commercial crop (soybeans or corn) sub-plots (c) and (d) were left alone and sub-plot (e) was burned annually. Vegetation was managed to exclude trees.

## 2.2 DREDGED MATERIAL AND SOIL SAMPLES.

2.2.1 Times Beach CDF and Black Rock Harbor CDF. Forty liters of unconsolidated dredged material were collected, in May 1985, from below 1 meter depth at Times Beach CDF and from Black Rock Harbor CDF and returned to the laboratory for use in earthworm uptake studies. Sub-samples of these materials were finely ground and oven dried for chemical analysis.

2.2.2 Times Beach CDF and Grand Island reference site. In November 1986, oxidized, surface layer material was collected using a 15cm depth by 5cm diameter soil corer from each of the thirteen sampling plots in vegetation zones A, B and C at Times Beach (Figure 1) and from each of the five sampling plots at Grand Island. These plots correspond with those used for collection of soil invertebrates. After extraction of the soil dwelling micro-invertebrates using a Tulgren funnel apparatus the material from four cores at each plot was mixed, finely ground and oven dried prior to chemical analysis.

2.2.3 Ottawa mine spoil reclamation site. Samples of dredged material from this site were collected in 1985 for analysis (Rhett & Richards, 1986).

## 2.3 LABORATORY UPTAKE STUDIES USING EISENIA FOETIDA.

Dredged material collected at the CDFs and soil from the reference site were returned to the laboratory for measuring metal uptake by earthworms. In each case a standard laboratory procedure was followed: 7.5 liter sub-samples of dredged material/soil were placed in replicate plexiglass cylinders and rewetted to field capacity. The plexiglass cylinders were covered at each end with muslin and one end was placed in a tray of de-ionized water. Capillary action produced a gradation in moisture content up the cylinder and earthworms could seek out their optimum conditions. Twenty grams (live weight) of mature, clitellate *Eisenia foetida* were added to each cylinder and held at 15°C under low light conditions for 28 days. Earthworms for use in the studies were grown in manure containing low concentrations of heavy metals and initial samples of the *E. foetida* were analyzed to ensure low metal concentrations. After 28 days exposure, earthworms were hand separated from the substrate and held on moist filter paper for 48 hours for evacuation of gut contents before preparation for metal analysis.

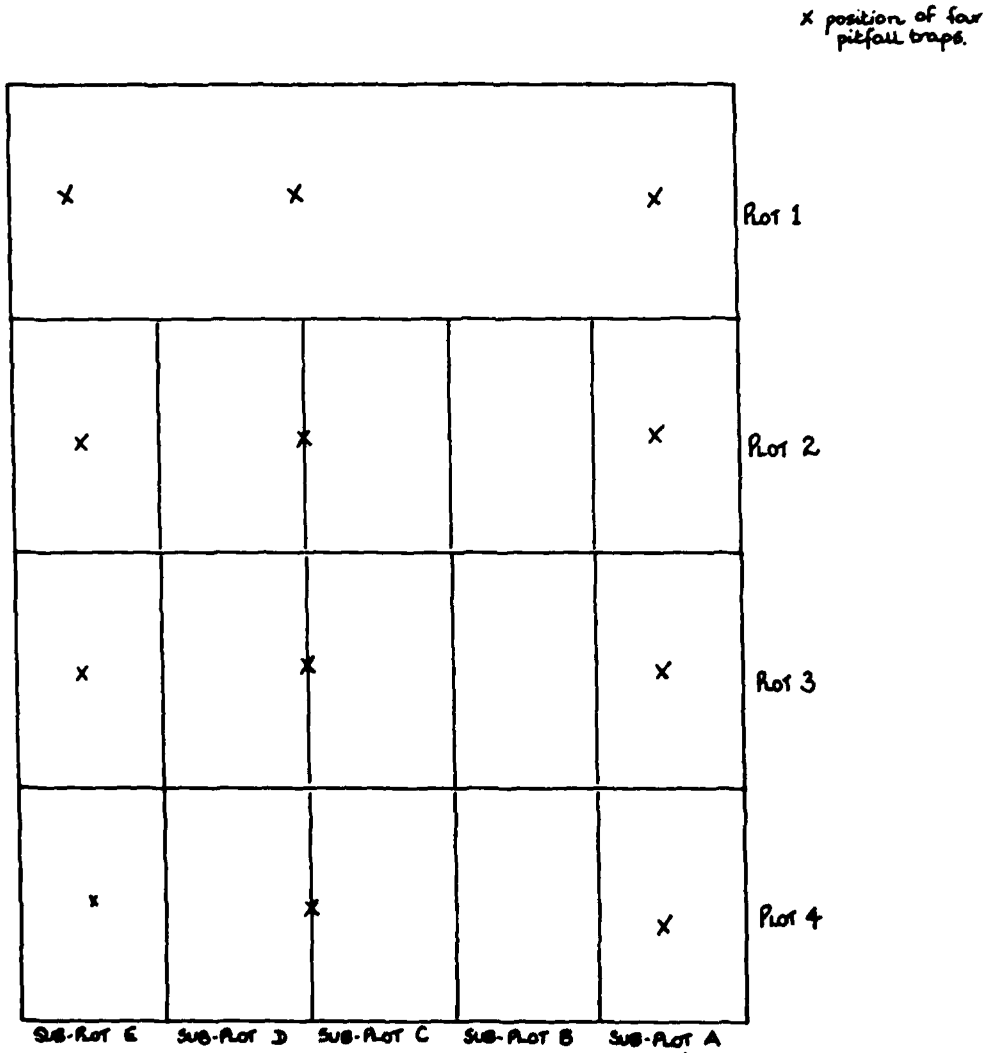


Figure 3: Ottawa, IL strip mine reclamation site - pitfall traps for the collection of invertebrates

2.3.1 Times Beach CDF. Dredged material has been collected on several occasions for use in laboratory uptake studies using the earthworm E. foetida. Under the present contract two studies were made:-

**Study 1**: In May 1985, 40 liters of deep layer (> 1 meter) unconsolidated dredged material were collected, returned to the laboratory and stored in sealed containers at 4°C until August 1985. Preliminary screening tests demonstrated that the material was toxic to E. foetida. Treatment of the dredged material by simulated weathering processes of leaching and drying was necessary before earthworms survived the 28 day exposure period. Dredged material was placed on polythene sheets in thin layers in a greenhouse to dry. Ten liters of water were poured through ten liter batches of dried sediment held on muslin. Fine sediment in the washings was removed by filtration and re-mixed with the re-dried sediment. After each leaching and drying earthworm survival was tested. Dredged material leached and dried five times was used for earthworm uptake studies.

**Study 2**: Dredged material was collected from thirteen plots in the upland area at Times Beach. Material collected from successive depths at each plot was held separately and earthworm uptake studies conducted using each layer. Successive layers were defined as follows: Level 0 = Litter layer; Level 1 = Humic layer; Level 2 = Oxidized Layer; Levels 3,4,5 = Oxidized/Reduced layers. Levels 3,4 and 5 are oxidized/reduced depending on seasonal changes in the water level of Lake Erie.

2.3.2 Grand Island reference area. Surface layer soil (to 30cm depth) was collected from four plots at Grand Island and returned to the laboratory for conducting earthworm uptake studies using the standard procedure.

2.3.3 Black Rock Harbor CDF. In preliminary tests, dredged material collected here was toxic to E. foetida. Simulated weathering processes as described in Section 2.3.1 were carried out. Earthworms then survived the standard procedure of 28 days exposure to the dredged material.

2.3.4 Ottawa mine spoil reclamation site. Earthworm uptake studies had been conducted previously at this site in 1981 and 1983. In 1981, uptake studies were conducted under field conditions within each plot at the site (Simmers et al., 1984) and in 1983, laboratory uptake studies were conducted using material collected from different depths at each plot. Results for plots 2 - 4 were then combined (Rhett et al., 1987). These results are referred to for comparison in the present report.

2.4 FIELD COLLECTION OF INVERTEBRATES.

Plots used for the collection of invertebrates were chosen to coincide with the different vegetation types at each of the sites.

Pitfall traps were placed in the dredged material/soil, at each plot, so that the top rim of the plastic cup was level with the surface of the soil. To each pitfall trap approximately 20 ml of 5% formaldehyde solution was added and the traps left in position for three to ten days. Invertebrates collected in the traps from each plot were rinsed free of debris and taxonomic groups identified. Invertebrates collected at the sites were identified by Mr John Bater of the Entomology Department, Ohio State University, USA and Mr James Ashby of the Entomology Department, Rothamsted Experimental Station, Harpenden, UK. The following taxonomic groups were used: Diplopoda (millipedes) and Chilopoda (centipedes) were grouped according to Class, the Class Arachnida was further divided into the Orders: Araneida (spiders) and Opiolones (harvestmen). The Class Insecta was further divided into the Orders Orthoptera (grasshoppers) and Coleoptera (beetles), and the Isopoda (woodlice) were grouped as an Order within the Class Crustacea. These groupings were chosen on the basis of biomass and numerical abundance of specimens collected in the traps and the diversity of species within the group. Within each group, further identification was carried out where expertise was available. In order to obtain sufficient biomass for chemical analysis, individuals of the same taxonomic group from the four traps at each plot were pooled. Invertebrates of each taxonomic group from each plot were oven-dried to constant weight at 80°C and their dry weight biomass recorded.

Native earthworms were collected using a dilute (0.5%) formaldehyde vermifuge applied to the surface (Raw, 1959). Emerging earthworms were immediately rinsed in clean water, separated according to species and prepared for analysis. The method of Stafford and McGrath (1986) was used to correct measurements of metal concentrations for the presence of soil within the earthworm gut. Earthworms were identified by Mr J. Reece Lofty of the Entomology Department, Rothamsted Experimental Station, Harpenden, Herts.

2.4.1 Times Beach CDF. For the collection of soil-dwelling invertebrates four plots were used in vegetation zones A and C (A1, A2, A3, A4, C1, C2, C3, C4) and five plots in vegetation zone B (B1, B2, B3, B4, B5) (Figure 1). In each plot, pitfall traps were positioned on the four corners of a meter square quadrat. Samples were collected in the spring and fall of 1985 and 1986. In spring 1985, for the initial investigation, seven of the thirteen possible plots were used and pitfall traps were left in position for three days before the contents were collected. For subsequent collections traps were left in position at all plots for ten days. A preliminary assessment of the native earthworm population was made in May 1985 and collection from within all plots was made in November 1986.

2.4.2 Grand Island reference site. In May and November 1986, pitfall traps were placed on the four corners of five, meter square plots at the Grand Island reference site, for ten days, to collect soil-dwelling invertebrates. In November 1986, dilute formaldehyde solution was applied at each plot to collect native earthworms.

2.4.3 Black Rock Harbor CDF. Within each of the twenty plots three pitfall traps were placed: two close to the walkway and one in the farther extremity of the plot (Figure 2). Pitfall traps were also placed outside the treated plots and along a transect running from the CDF across the dike and into the nearby vegetation (Figure 2). Pitfall traps were placed at Black Rock Harbor CDF for ten days in May and November 1986. There was no native earthworm population due to unfavorable conditions at the Black Rock Harbor CDF.

2.4.4 Ottawa mine spoil reclamation site. Within each of the differently managed subplots, except for sub-plot (b), pitfall traps were placed at the four corners of a meter square quadrat (Figure 3). Invertebrate collections were made over a ten day period in May 1986 and in November 1986. In May 1986 formalin vermifuge was applied in each sub-plot for the collection of native earthworms.

## 2.5 CHEMICAL ANALYSIS.

In preparation for metal analysis samples were oven dried at 80°C to constant weight. Total metal concentrations in the dredged material/soil and invertebrates were determined after a wet-ashing digestion procedure. Sample weights of less than or equal to 0.5g (dry weight) were digested in 'AnalaR' grade concentrated $HNO_3$ (5 ml) at room temperature for 48 hours, then refluxed at 125°C for 5 hours. After cooling, 'AnalaR' grade 70% $HClO_4$ was added before re-heating to 200°C, taking samples almost to dryness. Samples were then re-extracted in hot 25% HCl and made up to final volume (5% HCl). Concentrations of Zn, Cu, Ni, Cd, Cr and Pb were determined using inductively coupled plasma (ICP) emission spectrometry (ARL 34000 instrument). Standard solutions of these elements were prepared using the same extractant solution and reagent blanks were also run. In some cases (mostly invertebrates) insufficient biomass was available for analysis. In all circumstances due care was taken to avoid contamination by metals in the analytical procedures.

When making an assessment of the bioavailability of heavy metals, it is essential to distinguish between metal concentrations within the animal tissue and metal concentrations present as a result of soil in the sample, for example soil within the earthworm gut. For preliminary investigations and laboratory uptake studies, earthworms were held on moist filter paper for 48 hours (changed once after 24 hours) for gut evacuation. As this was not practicable in the field, a new method was developed using acid insoluble residue (AIR) as an inert marker to enable the quantity of soil present in any earthworm sample to be calculated. A correction factor could then be applied to eliminate heavy metal concentrations resulting from soil within the earthworm gut, leaving only the concentrations of heavy metals in the earthworm tissue. Full details of this method have been published elsewhere (Stafford and McGrath 1986).

## 2.6 STATISTICAL ANALYSIS.

Data comparisons were made using analysis of variance. Prior to this, the homogeneity of variance between the plots was tested using Cochran's test for homogeneity of variance. Where necessary, data transformations were carried out until valid comparisons could be made. Statistical comparisons between the means were achieved using Waller-Duncan k-ratio t-test. Where homogeneity of variance was not achieved by data transformation, comparisons between the means were carried out using non-parametric tests. Two non-parametric tests were applied as appropriate: if $k = 2$ the Mann-Whitney U test was applied, and if $k > 2$ the Kruskal-Wallis test was employed (Winer, 1979, Sokal and Rohlf, 1981). Where relevant, the method of comparison between the means has been indicated at the base of the appropriate table.

## 3. RESULTS.

### 3.1 DREDGED MATERIAL AND SOIL ANALYSIS.

3.1.1 Times Beach CDF and Black Rock Harbor CDF. Concentrations of heavy metals measured in the partly consolidated dredged material collected at Black Rock Harbor CDF and unconsolidated dredged material collected at Times Beach CDF for use in the laboratory earthworm uptake studies are given in Table 1. Although no statistical comparisons were possible because material was collected from only one plot at each site, major differences in metal concentrations were evident between the two CDFs.

Table 1

Metal Concentrations Measured in Dredged Material from Times Beach (Unconsolidated, Deep Layer) and Black Rock CDF (ug/g, dry weight).

| SITE | Element | | | | | |
|---|---|---|---|---|---|---|
| | Zn | Cu | Ni | Cd | Cr | Pb |
| Times Beach | 2,002 | 432 | 73 | 13 | 606 | 1,073 |
| Black Rock | 1,413 | 2,606 | 187 | 21 | 1,575 | 406 |

3.1.2 Times Beach CDF and Grand Island reference site. Concentrations of Zn, Cu, Ni, Cd, Cr and Pb in oxidized, surface layer dredged material from vegetation zones A, B and C, at Times Beach and in soil from the Grand Island reference site are given in Table 2.

Table 2

Metal Concentrations Measured in Dredged Material and Soil from Times Beach (Surface Layer) and Grand Island.

Mean values per zone expressed as ug/g, dry weight.

| SITE/ZONE | Element | | | | | |
|---|---|---|---|---|---|---|
| | Zn | Cu | Ni | Cd | Cr | Pb |
| Times Beach Vegetation zone | | | | | | |
| A | $289^{b}$ | $51^{a}$ | $28^{c}$ | $3.3^{b}$ | $57^{a}$ | $161^{a}$ |
| B | $480^{a}$ | $95^{a}$ | $49^{b}$ | $6.4^{a}$ | $137^{a}$ | $212^{a}$ |
| C | $426^{ab}$ | $83^{a}$ | $35^{b}$ | $5.0^{ab}$ | $100^{a}$ | $172^{a}$ |
| Grand Island | | | | | | |
| R | $227^{b}$ | $68^{a}$ | $55^{a}$ | $2.5^{c}$ | $37^{b}$ | $44^{b}$ |

a,b,c - mean values in a column followed by the same letter are not significantly different at $p<0.05$.
Non-parametric statistical comparison of the means was employed.

Concentrations of metals measured in dredged material from Times Beach and soil from Grand Island were statistically compared between vegetation zones at Times Beach and between each of the vegetation zones at Times Beach and the Grand Island site (Table 2). All comparisons were made at the 0.05 level of significance. Within Times Beach, Cu, Cr and Pb concentrations were not statistically different between the three vegetation zones. Cd and Zn concentrations were significantly lower in zone A compared with zone B but not zone C. Ni concentrations were significantly lower in zone A compared with zones B and C. Comparisons between Times Beach plots and Grand Island plots indicated significantly greater Cd, Cr and Pb concentrations in the Times Beach dredged material and significantly greater Ni concentrations in the Grand Island soil (Table 2). Concentrations of Cu at Times Beach and Grand Island were not statistically different.

3.1.3 Ottawa mine spoil reclamation site. Metal concentrations measured in dredged material placed at this site were compared (Table 3, from Rhett & Richards, 1986). Only Pb concentrations differed between the plots.

Table 3
Metal Concentrations Measured in Dredged Material from Ottawa Mine Spoil Reclamation Site.
Mean values expressed as ug/g, dry weight.

| PLOT | Element | | | | | |
|---|---|---|---|---|---|---|
| | Zn | Cu | Ni | Cd | Cr | Pb |
| Plot 2 | 1,003[a] | 85[a] | 38[a] | 6.9[a] | 83[a] | 412[a] |
| Plot 3 | 1,088[a] | 95[a] | 41[a] | 7.4[a] | 113[a] | 475[ab] |
| Plot 4 | 1,043[a] | 96[a] | 41[a] | 7.8[a] | 104[a] | 536[b] |

ab = values followed by different letters within each column are significantly different at the 95% confidence limit according to Bayes LSD test.

## 3.2 RESULTS OF LABORATORY UPTAKE STUDIES.

### 3.2.1 Times Beach (unconsolidated layer) and Black Rock dredged material.

Preliminary investigations demonstrated that survival of E. foetida in these materials was poor ($LT_{100}$ of <2 days and <3 hours in Times Beach and Black Rock materials, respectively, Table 4). To conduct a 28 day uptake study, some pretreatment of the materials was necessary. Leaching and drying of the material aimed to simulate natural weathering processes and increase acceptability of the materials to the earthworms. Results of successive tests for earthworm mortality after each leaching and drying are given in Table 4. Once suitable for 28 day earthworm survival, materials were used to conduct the uptake study. After 28 days exposure to the dredged material, 50% of the earthworm biomass was recovered from the Times Beach material and 56% from the Black Rock material (mean values of four replicates). Results of metal concentrations in E.foetida are given in Table 5.

Table 4
LT$_{50}$ and LT$_{100}$ of E. foetida after Successive Leaching and Drying of the Dredged Material

| Treatment | | TIMES BEACH | BLACK ROCK |
|---|---|---|---|
| No treatment | LT$_{50}$ | 1 - 4 days | |
| | LT$_{100}$ | (0% mortality after 1 day)<br>(100% mortality after 4 days) | < 3 hours |
| Once leached and dried | LT$_{50}$ | <2 days | |
| | LT$_{100}$ | (92% mortality after 4 days) | <3 hours |
| Twice leached and dried | LT$_{50}$ | 2 - 3 days<br>(33% mortality after 2 days)<br>(58% mortality after 3 days) | 3 - 7 days<br>(42% mortality after 3 days)<br>(75% mortality after 7 days) |
| | LT$_{100}$ | <7 days<br>(92% mortality after 7 days) | >7 days |
| Thrice leached and dried | LT$_{50}$ | 7 - 12 days<br>(0% mortality after 7 days)<br>(92% mortality after 12 days) | >12 days<br>(42% mortality after 12days) |
| | LT$_{100}$ | >12 days | >12 days |
| Four times leached/dried | LT$_{50}$ | 17 - 28 days<br>(33% mortality after 17 days)<br>(50% mortality after 28 days) | 17 - 28 days<br>(17% mortality after 17days)<br>(92% mortality after 28days) |
| | LT$_{100}$ | >28 days | >28 days |
| Five times leached/dried | -------- | >80% survival after 28 days | ----------------- |

Earthworms were considered dead if they failed to respond to a sharp stimulus to the anterior end.

Table 5
Metal Concentrations (ug/g, dry weight) in E. foetida at the Start of the Study (Initial) and After 28 Days Exposure to the Dredged Materials.

| ELEMENT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Initial worms | 120<br>(1.9) | 17<br>(0.93) | 1.4<br>(0.97) | 2.8<br>(0.32) | 1.4<br>(0.67) | 2.7<br>(0.21) |
| After 28 days: | | | | | | |
| Times Beach | 135<br>(5.6) | 41<br>(2.2) | 27<br>(5.3) | 5.4<br>(0.45) | 2.0<br>(1.9) | 13<br>(4.3) |
| Black Rock | 152<br>(8.1) | 145<br>(7.6) | 33<br>(6.7) | 8.0<br>(1.6) | 7.2<br>(5.5) | 4.5<br>(0.31) |

Mean value and standard deviation (in parenthesis) of four replicates.

3.2.2 Times Beach consolidated dredged material. E. foetida were exposed for 28 days to dredged material from Times Beach CDF, and to a control substrate of uncontaminated horse manure. Dredged material was excavated from increasing depths at Times Beach and earthworm uptake studies conducted using each of the different levels separately. Metal concentrations measured in the earthworms after 28 days are given in Table 6.

Table 6

Metal Concentrations Measured in E. foetida Exposed to Times Beach Dredged Material and an Uncontaminated Control Substrate.

| Substrate | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Control: | 110 | 9.9 | 1.3 | 4.0 | 5.5 | <2.7 |
| n=3 | (11) | (0.46) | (0.50) | (2.2) | (4.1) | - |
| **Vegetation zone A** | | | | | | |
| Level:0(litter) | 179 | 15 | 5.9 | 15 | 3.4 | 5.5 |
| n=3 | (97) | (1.1) | (5.7) | (7.3) | (0.91) | (0.15) |
| Level:1(humic) | 114 | 18 | 8.3 | 13 | 6.9 | 9.1 |
| n=3 | (7.9) | (1.2) | (9.5) | (5.5) | (4.2) | (5.4) |
| Level:2(oxidized) | 112 | 29 | 2.9 | 6.1 | 7.7 | 8.7 |
| n=3 | (2.8) | (5.2) | (0.96) | (0.84) | (3.7) | (3.5) |
| Level:3 | 107 | 22 | 3.6 | 6.4 | 12 | 13 |
| n=2 | | | | | | |
| **Vegetation zone B** | | | | | | |
| Level:0(litter) | 113 | 12 | 1.7 | 17 | 1.5 | 2.7 |
| n=3 | (7.1) | (1.8) | (0.82) | (4.1) | (0.53) | (0.07) |
| Level:1(humic) | 110 | 18 | 2.9 | 12 | 5.1 | 4.9 |
| n=3 | (0.60) | (3.4) | (0.76) | (2.9) | (0.80) | (0.93) |
| Level:2(oxidized) | 115 | 23 | 3.5 | 6.4 | 11 | 9.7 |
| n=3 | (4.8) | (1.5) | (0.35) | (1.3) | (3.4) | (1.7) |
| Level:3 | 133 | 35 | 4.9 | 5.6 | 19 | 24 |
| n=3 | (16) | (0.61) | (0.64) | (0.60) | (4.5) | (6.5) |
| **Vegetation zone C** | | | | | | |
| Level:0(litter) | 112 | 12 | 3.3 | 17 | 6.1 | 3.5 |
| n=4 | (7.8) | (1.2) | (3.2) | (10) | (9.0) | (0.76) |
| Level:1(humic) | 126 | 14 | 3.6 | 11 | 5.2 | 6.4 |
| n=4 | (22) | (1.2) | (1.7) | (2.9) | (1.2) | (2.3) |
| Level:2(oxidized) | 114 | 24 | 3.5 | 7.3 | 14 | 11 |
| n=4 | (11) | (3.7) | (0.83) | (2.3) | (5.6) | (8.7) |
| Level:3 | 138 | 34 | 3.1 | 7.2 | 24 | 26 |
| n=2 | | | | | | |
| Level:4 | 116 | 34 | 2.9 | 5.8 | 10 | 14 |
| n=2 | | | | | | |

Mean values and standard deviation (in parenthesis) in ug/g, dry weight.

These results are compared statistically between vegetation types at Times Beach in Table 7a and between successive levels in the substrate in Table 7b.

Table 7a

Metal Concentrations Measured in E. foetida Exposed to Dredged Material from Different Vegetation Types at Times Beach CDF. All values expressed as ug/g, dry weight.

| Level/Veg. type | Zn | Cu | Cd | Pb |
|---|---|---|---|---|
| Level 0 | | | | |
| Veg. type A | $179_a$ | $15_a$ | $15_a$ | $5.5_a$ |
| Veg. type B | $113_a$ | $12_a$ | $17_a$ | $2.7_a$ |
| Veg. type C | $112_a$ | $12_a$ | $17_a$ | $3.5_a$ |
| Level 1 | | | | |
| Veg. type A | $114_a$ | $18_a$ | $13_a$ | $9.1_a$ |
| Veg. type B | $110_a$ | $18_a$ | $12_a$ | $4.9_a$ |
| Veg. type C | $126_a$ | $14_b$ | $11_a$ | $6.4_a$ |
| Level 2 | | | | |
| Veg. type A | $112_a$ | $29_a$ | $6.1_a$ | $8.7_a$ |
| Veg. type B | $115_a$ | $23_a$ | $6.4_a$ | $9.7_a$ |
| Veg. type C | $114_a$ | $24_a$ | $7.3_a$ | $11_a$ |

a = mean values in a column within each level with the same subscript are not significantly different ($p < 0.05$).

Table 7b

Metal Concentrations Measured in E. foetida Exposed to Dredged Material from Different Depths at Times Beach CDF. All values expressed as ug/g, dry weight.

| Veg. type/Level | Zn | Cu | Cd | Pb |
|---|---|---|---|---|
| Vegetation type A | | | | |
| Level 0 | $179_a$ | $15_a$ | $15_a$ | $5.5_a$ |
| Level 1 | $114_a$ | $18_a$ | $13_a$ | $9.1_a$ |
| Level 2 | $112_a$ | $29_a$ | $6.1_a$ | $8.7_a$ |
| Vegetation type B | | | | |
| Level 0 | $113_a$ | $12_b$ | $17_a$ | $2.7_a$ |
| Level 1 | $110_a$ | $18_b$ | $12_b$ | $4.9_a$ |
| Level 2 | $115_a$ | $23_a$ | $6.4_b$ | $9.7_a$ |
| Vegetation type C | | | | |
| Level 0 | $112_a$ | $12_b$ | $17_a$ | $3.5_b$ |
| Level 1 | $126_a$ | $14_b$ | $11_a$ | $6.4_b$ |
| Level 2 | $114_a$ | $24_a$ | $7.3_a$ | $11_a$ |

ab = mean values in a column within each vegetation type with different subscripts are significantly different ($p < 0.05$)

3.2.3 Grand Island reference site. Over 50% of the biomass of *E. foetida* exposed to soil from the Grand Island site were recovered at the end of the 28 days. Metal concentrations in these earthworms and those sampled at the start of the 28 day study (T = 0) are given in Table 8.

Table 8
Metal Concentrations Measured in *E. foetida* at the Beginning and End of 28 Days Exposure to the Grand Island Soil.
Mean values and standard deviations (in parenthesis) in ug/g, dry weight.

| Sample | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| T = 0 | 98 (4.2) | 9.0 (0.62) | 2.5 (0.31) | 2.7 (0.23) | 2.1 (0.93) | <4.2 |
| T = 28 days | 101 (4.5) | 10 (0.56) | 5.9 (5.5) | 4.4 (0.19) | 2.1 (0.47) | <2.7 |

T = 0 = mean value and standard deviation of three replicate samples.
T = 28 = mean value and standard deviation of four replicate samples.

3.2.4 Ottawa mine spoil reclamation site. Results of earthworm uptake studies conducted in the field in 1981 (Simmers et al., 1984) and in the laboratory in 1983 (Rhett et al., 1987) are given in Tables 9a and b, respectively.

Table 9a
Metal Concentrations in *E. foetida* Exposed to Dredged Material in the Field at the Ottawa Site.
Mean values ± standard deviations in ug/g, dry weight.

| Plot | Cu | Ni | Cd | Pb |
|---|---|---|---|---|
| Control* | 7.5 ± 1.1 | 5.6 ± 2.5 | 3.1 ± 0.34 | 1.3 ± 0.85 |
| 2 | 14 ± 1.7 | 5.2 ± 1.4 | 2.9 ± 0.70 | 2.2 ± 0.65 |
| 3 | 11 ± 0.5 | 5.5 ± 0.21 | 3.0 ± 0.39 | 5.4 ± 1.1 |
| 4 | 21 ± 0.5 | 7.6 ± 0.83 | 9.7 ± 0.39 | 3.6 ± 0.42 |

Control* = earthworms from a manure/peat moss substrate of low metal concentrations.
From Simmers et al., 1984.

Table 9b
Metal Concentrations in Earthworms Exposed to Leaf Litter and Dredged Material from Plots 2-4 at the Ottawa Site.
Mean values ± standard deviations in ug/g, dry weight.

| Test Material | Cu | Ni | Cd | Pb |
|---|---|---|---|---|
| Initial worms | 9.6 ± 1.0 | 2.0 ± 0.77 | 3.7 ± 0.51 | 1.5 ± 0.65 |
| After 28 days exposure: | | | | |
| E. foetida | 9.2 ± 1.6 | 1.9 ± 0.46 | 14 ± 5.4 | 2.2 ± 0.46 |
| Leaf litter | 16 ± 1.7 | 5.9 ± 0.20 | 3.3 ± 0.73 | < |
| E. foetida | 26 ± 4.2 | 5.2 ± 0.61 | 9.0 ± 0.89 | 2.9 ± 0.69 |
| 30cm depth* | 127 ± 8.6 | 52 ± 3.2 | 10 ± 0.50 | 620 ± 70 |
| E. foetida | 25 ± 1.0 | 5.3 ± 0.31 | 8.2 ± 0.21 | 5.3 ± 2.0 |
| 100cm depth* | 117 ± 10 | 50 ± 2.2 | 9.2 ± 1.6 | 585 ± 23 |

depth* = defines depth below the surface from which dredged material was collected.
From Rhett et al., 1987.

3.3 IDENTIFICATION AND ANALYSIS OF NATIVE INVERTEBRATES.

3.3.1 Times Beach CDF. Individuals from most of the major invertebrate taxa were represented in the pitfall traps. Specimens of Coleoptera (beetles), Araneida (spiders), Opiolones (harvestmen), Chilopoda (centipedes), Diplopoda (millipedes), Isopoda (woodlice) and Orthoptera (grasshoppers) collected in the pitfall traps were identified and counted. Eleven families of Coleoptera were represented dominated numerically by the Carabidae (Ground Beetles); four families of Isopoda were present dominated numerically by Trichoniscus (Woodlice); two families of Diplopoda and one family each of Chilopoda and Araneida were recorded in the samples collected at each sampling time. A full record of species collected and identified is included in Appendix A, to this report. In composition the invertebrate fauna collected in the pitfall traps was dominated both numerically and in terms of dry matter contribution to the total biomass by Coleoptera, Diplopoda and Isopoda. Relative percent biomass of each group in the pitfall traps is given in Appendix A, Tables 1c, 2c, 3b and 4b. Pitfall traps collect proportionally more of the active groups, such as predatory species, actively seeking prey, and detritivores moving about in the litter and on the soil surface. Herbivorous invertebrates are poorly represented. Pitfall trapping is not intended to provide a means of estimating absolute invertebrate populations.

Invertebrates were sampled using pitfall traps in spring and fall for two consecutive years. Seasonal differences between samples in terms of species abundance and composition were evident for some taxonomic groups, for example, Opiolones and Orthoptera were collected in greater abundance in the pitfall traps collected in the fall compared with the spring. Snails were present in larger numbers in the sample collected in November compared to other samples. Within taxonomic groups (where further identification to genus level was possible) some differences between seasons were also observed, for example, in the May 1985 sample there were no Nitidulidae (Sap Beetles) or Chrysomelidae (Leaf Beetles) among the Coleoptera, while in the October 1985 sample the Elateridae (Click Beetles), Tachyporidae (Carrion Beetles) and Oxytelinidae (Carrion Beetles) which were present in May were absent. These differences in composition between the samples are most likely to be due to seasonal breeding cycles of the different species of invertebrates.

The greatest numbers and percentage biomass by weight collected in the traps were the Coleoptera, followed by the Isopoda. A similar total dry weight biomass was collected in all the pitfall traps across the site. The composition of invertebrate fauna in the traps was then examined for changes in taxonomic composition which could be related to vegetation type. A similar relative biomass of Coleoptera was collected from all plots across the upland area at the site. Some indication of an increase in relative percent by weight of Araneida and decrease in relative percent by weight of Diplopoda and Isopoda in the pitfall traps may have occurred with increasing proximity to the water edge. This may be related to the changing vegetation type, or may be directly due to higher moisture levels in the substrate.

3.3.2 Grand Island reference site. Pitfall traps placed at the Grand Island site collected a similar taxonomic composition of soil-dwelling invertebrates to those identified from the Times Beach traps (Appendix B, Tables 1 and 2). In similarity to the Times Beach results, numbers and biomass of invertebrates were dominated by the Coleoptera and Isopoda and similar seasonal differences were noted, for example Opiolones and Orthoptera were present in the November sample and not in the May sample.

Measurements of metal concentrations in invertebrates collected at Times Beach CDF and Grand Island reference site are presented in full detail in Appendices A and B. For each taxonomic group, mean metal concentrations were calculated and statistically compared at each of the four sampling times (1985, spring and fall and 1986, spring and fall). The results of these statistical analyses are shown in Tables 10a-d.

In 1985, the Grand Island reference site was not sampled by pitfall trapping; however, statistically significant differences in metal concentrations were noted between the vegetation zones at Times Beach. In the spring sample (Table 10a), Zn and Cd concentrations in the Coleoptera were significantly lower in vegetation zone A compared with zones B and C. Cd concentrations in the Diplopoda were significantly greater in vegetation zone B compared with zones A and C and a similar pattern was noted for Cu concentrations in the Araneida. In fall 1985 (Table 10b), no statistically significant differences were noted between the vegetation zones at Times Beach for any of the four taxa, with the exception of the Isopoda, where Cu concentrations were significantly greater in Isopoda from vegetation zone A compared with zones B and C.

Table 10a

Metal Concentrations Measured in Invertebrates Collected in Pitfall Traps, Times Beach, Spring 1985.

Mean values per vegetation zone[1] expressed in ug/g, dry weight.

| SPECIES/ ZONE | Element Zn | Cu | Cd | Pb |
|---|---|---|---|---|
| **ARANEIDA** | | | | |
| Veg. zone A | 415$^{a}$ | 169$^{b}$ | 27$^{a}$ | 26$^{a*}$ |
| B | 461$^{a}$ | 230$^{a}$ | 76$^{a}$ | 17$^{a*}$ |
| C | 307$^{a}$ | 182$^{b}$ | 111$^{a}$ | 6.8$^{a*}$ |
| COLEOPTERA | | | | |
| Veg. zone A | 90$^{b}$ | 14$^{a*}$ | 1.1$^{b}$ | 0.68$^{a}$ |
| B | 108$^{a}$ | 15$^{a*}$ | 2.7$^{a}$ | 2.4$^{a}$ |
| C | 113$^{a}$ | 15$^{a*}$ | 2.2$^{a}$ | 2.9$^{a}$ |
| *DIPLOPODA* | | | | |
| Veg. zone A | 211$^{a}$ | 641$^{a}$ | 2.8$^{b}$ | 7.5$^{a}$ |
| B | 242$^{a}$ | 660$^{a}$ | 3.7$^{a}$ | 6.1$^{a}$ |
| C | 174$^{a}$ | 634$^{a}$ | 2.2$^{b}$ | 5.8$^{a}$ |
| ISOPODA | | | | |
| Veg. zone A | 180$^{a}$ | 182$^{a}$ | 33$^{a*}$ | 14$^{a*}$ |
| B | 191$^{a}$ | 142$^{a}$ | 45$^{a*}$ | 14$^{a*}$ |
| C | 180$^{a}$ | 144$^{a}$ | 29$^{a*}$ | 11$^{a*}$ |

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

1. Mean values of two replicates for vegetation zones A and B, and three replicates for vegetation zone C.

Table 10b

Metal Concentrations Measured in Invertebrates Collected in Pitfall Traps, Times Beach, Fall 1985.

Mean values per vegetation zone[1] expressed in ug/g, dry weight.

| SPECIES/ ZONE | | Element Zn | Cu | Cd | Pb |
|---|---|---|---|---|---|
| ARANEIDA | | | | | |
| Veg. zone | A | 166[a] | 111[a] | 15[a] | 9.0[a] |
| | B | 140[a] | 77[a] | 8.8[a] | 14[a] |
| | C | 142[a] | 103[a] | 18[a] | 8.5[a] |
| COLEOPTERA | | | | | |
| Veg. zone | A | 99[a] | 18[a] | 2.1[a] | 7.1[a] |
| | B | 111[a] | 19[a] | 2.6[a] | 5.0[a] |
| | C | 104[a] | 16[a] | 1.6[a] | 4.5[a] |
| DIPLOPODA | | | | | |
| Veg. zone | A | 195[a]* | 728[a] | 2.7[a] | 12[a] |
| | B | 235[a]* | 787[a] | 3.1[a] | 12[a] |
| | C | 210[a]* | 723[a] | 3.0[a] | 12[a] |
| ISOPODA | | | | | |
| Veg. zone | A | 314[a] | 310[a] | 23[a] | 17[a] |
| | B | 326[a] | 223[b] | 22[a] | 16[a] |
| | C | 281[a] | 208[b] | 23[a] | 13[a] |

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

1. Mean values of four replicates in vegetation zones A and C, and five replicates in vegetation zone B.

s - insufficient data available for statistical analysis.

In 1986, pitfall traps were placed at both the Times Beach CDF and the Grand Island reference site and the results of metal analysis of these samples are statistically compared in Tables 10c and 10d. At Times Beach, there were no statistically significant differences between the vegetation zones, with the exception of significantly greater Zn concentrations were measured in the Coleoptera from vegetation zone A compared with vegetation zones B and C (Table 10c) and significantly greater Cu concentrations in the Araneida from vegetation zone A compared with vegetation zone C, but not B (Table 10d).

Table 10c
Metal Concentrations Measured in Invertebrates Collected in Pitfall Traps, Times Beach (A,B,C) and Grand Island (R), Spring 1986.
Mean values per vegetation zone[1] expressed in ug/g, dry weight.

| SPECIES/ ZONE | Zn | Cu | Cd | Pb |
|---|---|---|---|---|
| ARANEIDA | | | | |
| Veg. zone A | 325[a] | 230[a] | 71[a] | s |
| B | 311[a] | 177[a] | 36[a] | s |
| C | 299[a] | 114[a] | 29[a] | s |
| R | 238[a] | 202[a] | 13[a] | s |
| COLEOPTERA | | | | |
| Veg. zone A | 147[a] | 18[a] | 4.7[a] | s |
| B | 109[b] | 18[a] | 4.4[a] | s |
| C | 105[b] | 19[a] | 3.5[a] | s |
| R | 102[b] | 15[a] | 2.0[a] | s |
| DIPLOPODA | | | | |
| Veg. zone A | 269[a]* | 683[a] | 3.9[a] | 22[a] |
| B | 227[a]* | 681[a] | 4.0[a] | 16[a] |
| C | 254[a]* | 755[a] | 4.1[a] | 14[a] |
| R | 198[a]* | 218[b] | 2.7[a] | s |
| ISOPODA | | | | |
| Veg. zone A | 341[a] | 224[a] | 21[a] | 21[a] |
| B | 307[a] | 221[a] | s | s |
| C | 272[a] | 185[ab] | 20[a] | 16[a] |
| R | 260[a] | 153[b] | 3.3[b] | 6.5[a] |

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.
* = Non-parametric statistical comparison of the means was employed.
1. Mean values of four replicates for vegetation zones A and B, and five replicates for vegetation zone C and the Grand Island site: R.
s = insufficient sample size for statistical analysis.

Table 10d
Metal Concentrations Measured in Invertebrates Collected in Pitfall Traps, Times Beach (A,B,C) and Grand Island (R), Fall 1986.
Mean values per vegetation zone[1] expressed in ug/g, dry weight.

| SPECIES/ ZONE | Element Zn | Cu | Cd | Pb |
|---|---|---|---|---|
| **ARANEIDA** | | | | |
| Veg. zone A | 213[a] | 85[a] | 8.6[a]* | 6.7[a] |
| B | 215[a] | 78[ab] | 14[a]* | 7.2[a] |
| C | 209[a] | 64[b] | 7.3[a]* | 6.6[a] |
| R | 194[a] | 64[b] | 3.9[b]* | 17[a] |
| **COLEOPTERA** | | | | |
| Veg. zone A | 114[a]* | 31[a]* | 2.7[a] | 2.5[a] |
| B | 100[a]* | 18[a]* | 2.7[a] | 5.0[a] |
| C | 90[a]* | 19[a]* | 2.5[a] | 7.1[a] |
| R | 63[a]* | 16[a]* | 1.1[a] | 3.8[a] |
| **DIPLOPODA** | | | | |
| Veg. zone A | 235[a] | 522[a] | 4.5[a] | 14[a] |
| B | 260[a] | 557[a] | 4.5[a] | 19[a] |
| C | 222[a] | 469[a] | 4.2[a] | 12[a] |
| R | 160[a] | 133[b] | 2.4[a] | 6.3[b] |
| **ISOPODA** | | | | |
| Veg. zone A | 234[a] | 130[a]* | 30[a] | 18[a] |
| B | 297[a] | 101[a]* | 27[a] | 17[a] |
| C | 332[a] | 186[a]* | 23[a] | 17[a] |
| R | 219[a] | 79[a]* | 8.2[b] | 14[a] |

a,b - mean values in a column within each taxon followed by the same letter are not significantly different at $p < 0.05$.
* = Non-parametric statistical comparison of the means was employed.
1. Mean values of four replicates for vegetation zones A and B, and five replicates for vegetation zone C and the Grand Island site: R.

Statistically significant differences between the samples collected at Times Beach and those collected at Grand Island could be assessed in the 1986 samples (Tables 10c and d). In both the spring and fall samples Cu concentrations in the Diplopoda and Cd concentrations in the Isopoda were significantly greater at Times Beach compared with Grand Island. In spring 1986, Zn concentrations measured in Coleoptera from the Grand Island site were significantly lower than those measured in Coleoptera collected in vegetation zone A but not B and C at Times Beach, and Cu concentrations in the Isopoda were significantly lower at Grand Island compared to vegetation zones A and B, but not C at Times Beach. Araneida, collected in fall 1986, had significantly lower Cd concentrations at Grand Island compared to Times Beach, and significantly lower Cu concentrations at Grand Island compared to vegetation zone A at Times Beach. Also in fall 1986, Diplopoda collected at Grand Island had significantly lower Pb concentrations compared with those collected at Times Beach.

In summary, Tables 10a-d indicated no significant differences in Pb concentrations within each taxon, between the vegetation zones at Times Beach or (with the sole exception of the Diplopoda collected in fall 1986) between Times Beach and Grand Island. Concentrations of Cu in the Diplopoda and Cd in the Isopoda were consistently greater ($p < 0.05$) in the Times Beach samples compared with the Grand Island samples. Patterns of metal concentrations measured in the various taxa at the two sites were clearly repeated at each time of sampling. Figures 4a-d show the metal concentrations measured within each group of invertebrates, by metal element, for each sampling period.

In general, concentrations did not appear to differ according to the time of year that the sample was collected. The most notable exception was concentrations of Zn, Cu and Cd in the Araneida which were elevated in the spring sample compared with the fall sample in both 1985 and 1986. This pattern was clearly evident from Figures 4a-d. Since expertise was not available to identify the Araneida to genus or species level, it was not possible to ascertain whether this was due to a variation in species composition at the different times of year. However, some assessment of inter-generic and intra-specific variation was made using the Isopoda and the Lumbricus rubellus collected at Times Beach. The results of this study are given in Appendix E and demonstrate the importance of accurate identification of target/indicator organisms in making an assessment of the mobility of metals into the food chains. Over the two year sampling period there may have been an increase in the Cd concentrations present in the Coleoptera, Opiolones and Diplopoda collected; however, this increase would need to be validated through analysis of further samples as time progresses.

Differences in metal concentrations between taxonomic groups were clearly evident from the results of chemical analysis and are shown in Figures 4a-d. Within the carnivorous species, the predatory Coleoptera contained the lowest concentrations of metals and Araneida the highest. Other carnivorous groups (Chilopoda and Opiolones) also contained high concentrations of the elements Zn, Cu, and Cd. The detritivorous species (Diplopoda and Isopoda), had high concentrations of the elements Zn, Cu and Cd, and greater Cd, and lower Cu concentrations were observed in the Isopoda compared with the Diplopoda. With the exception of Cd concentrations, the two herbivorous groups analyzed (herbivorous Coleoptera and Orthoptera) had similar tissue metal concentrations. Cd concentrations were greater in the Orthoptera. All metal concentrations in herbivorous groups were low compared with the carnivorous and detritivorous groups. Of the taxonomic groups collected in sufficient quantities for metal analysis the Araneida, Diplopoda and Isopoda contained the greatest concentrations of heavy metals.

3.3.3 Black Rock Harbor CDF. Due to the relatively recent disposal of dredged material, invertebrates collected in pitfall traps placed at this site were relatively mobile groups (Coleoptera and Araneida) likely to be moving in and out of the site to feed. No soil-inhabiting invertebrates and very few detritivores were collected within the CDF. Details of the invertebrates collected within Black Rock Harbor CDF and along the transect out of the site and metal concentrations measured in each of the taxonomic groups are given in Appendix C. Due to the high mobility of the organisms collected, it was unlikely that individuals remained within any specific sub-plot and therefore mean concentrations for each taxonomic group collected within the CDF are

Figure 4 a-d: Metal Concentrations in Invertebrates
Captured in Pitfall Traps at Times Beach and Grand Island.

Key to symbols:

Taxon: A = ARANEIDA
C = COLEOPTERA
D = DIPLOPODA
I = ISOPODA

Season: F = Fall
S = Spring

Zone: A = Vegetation zone A, Times Beach
B = Vegetation zone B, Times Beach
C = Vegetation zone C, Times Beach
R = Reference site, Grand Island

All concentrations expressed as ug/g, dry weight.

Figure 4a Zinc concentrations in Invertebrates in 1985 and 1986
Figure 4b Copper concentrations in Invertebrates in 1985 and 1986
Figure 4c Cadmium concentrations in Invertebrates in 1985 and 1986
Figure 4d Lead concentrations in Invertebrates in 1985 and 1986

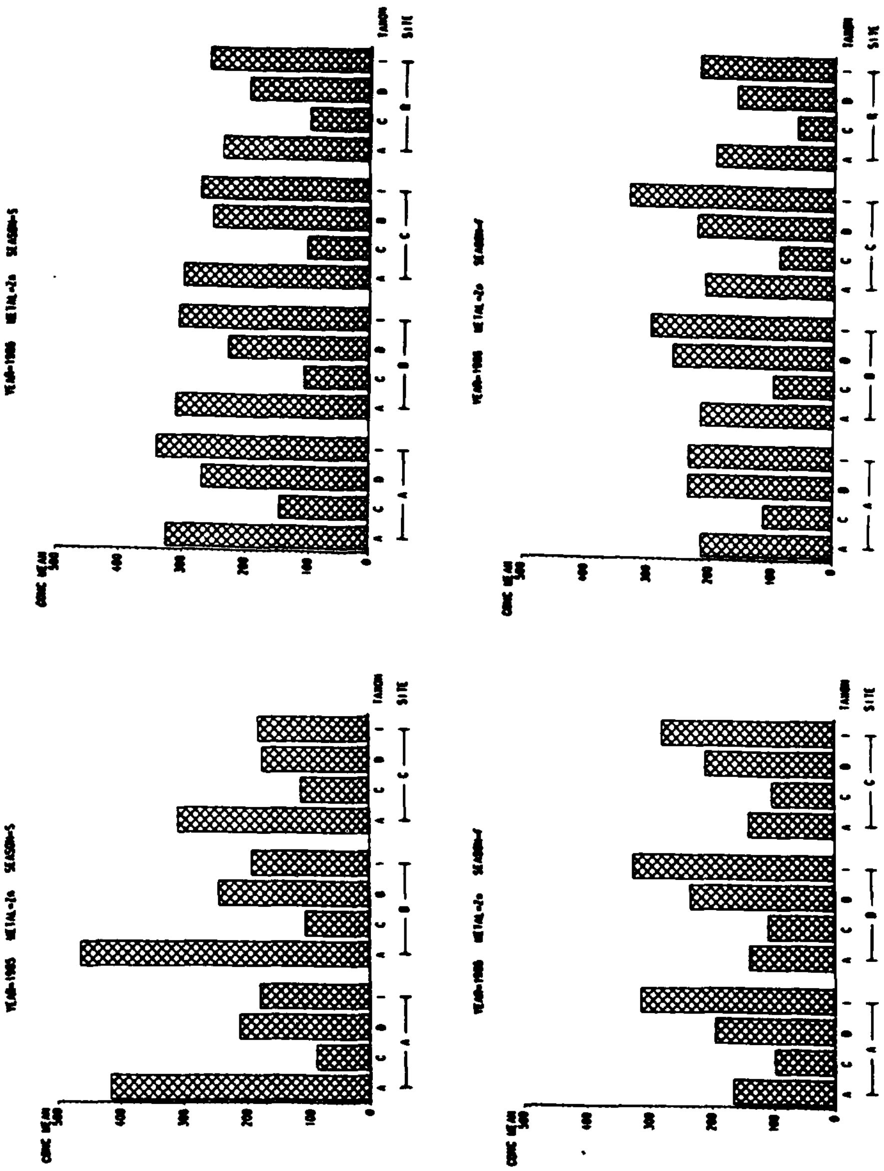

Figure 4a: Zinc

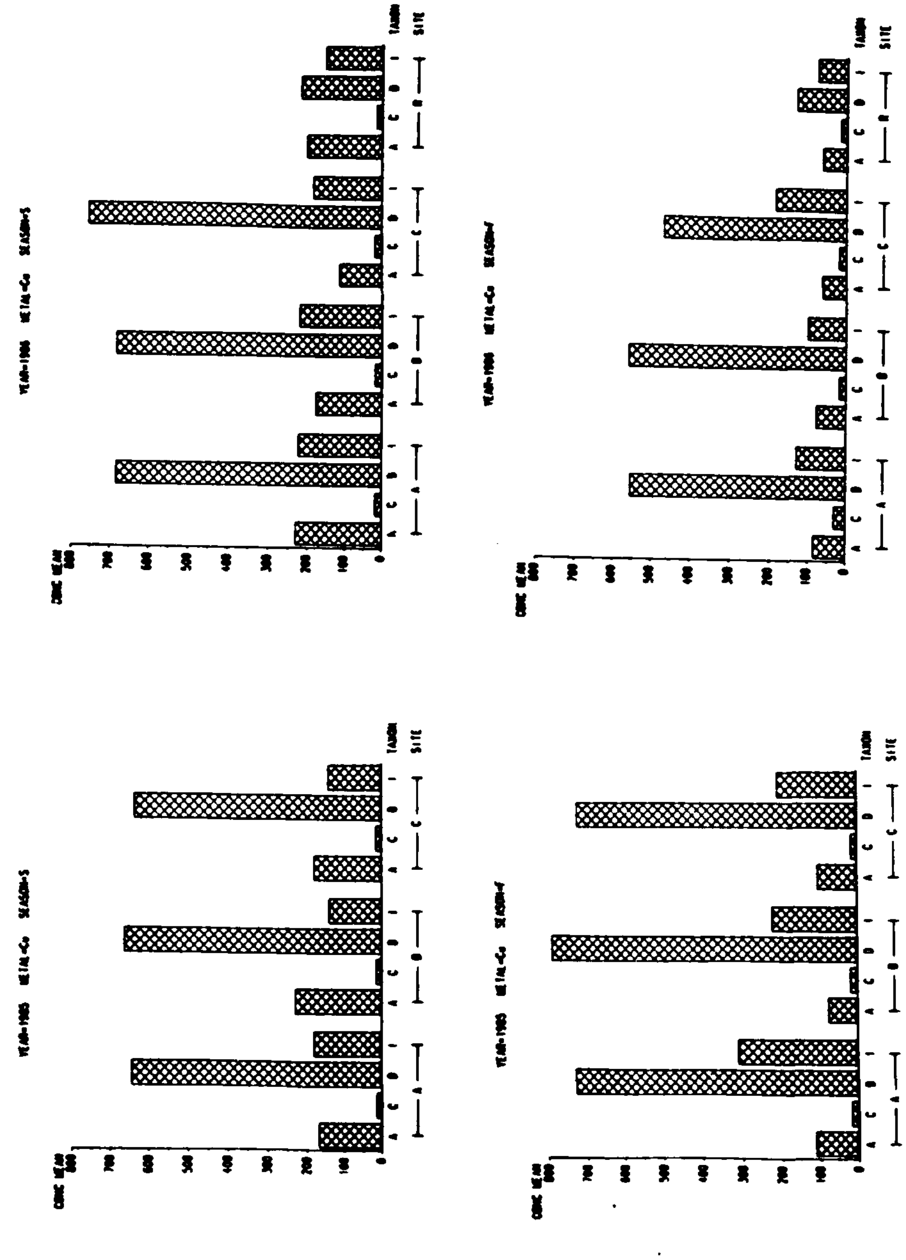

Figure 4b; Copper

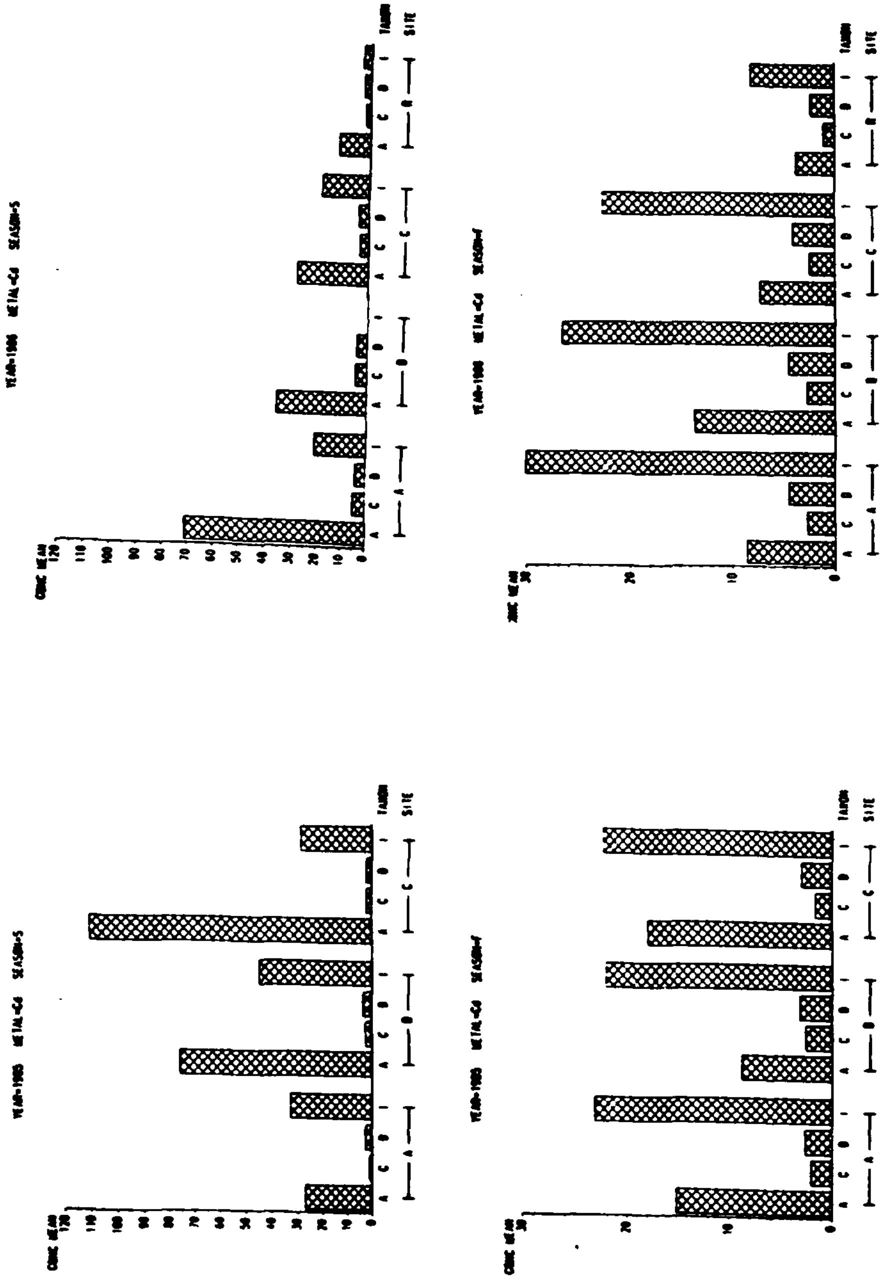

Figure 4c; Cadmium

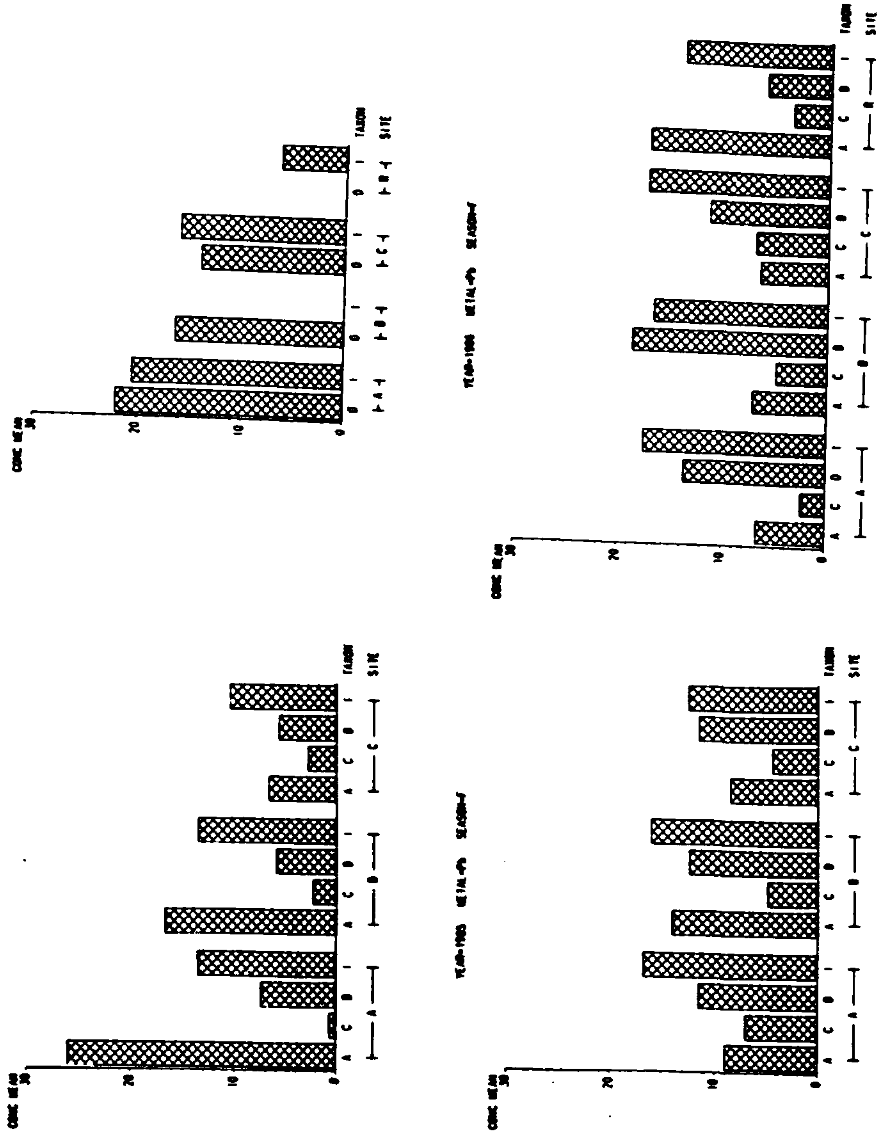

Figure 4d: Lead

given in Table 11. The major difference between invertebrates collected in May and November was the abundance of Coleoptera larvae collected in November. These larvae are likely to have remained only within the CDF and metal concentrations (particularly Cu) did reflect the high metal concentrations at this CDF (Table 11). The seasonal differences noted in metal concentrations in Araneida collected at Times Beach (Tables 10a-d) were observed for Ni and Cd at Black Rock, but not for Zn or Cu, however high metal concentrations did reflect high metal concentrations at this CDF (Tables 1 and 11).

Table 11
Metal Concentrations in Soil Invertebrates Collected within the Black Rock CDF in Spring and Fall 1986.
All concentrations in ug/g, dry weight.

| Species/Sample | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Predatory Coleoptera | | | | | | |
| May 1986 | 80 | 64 | 4.4 | 1.1 | 33 | 9.3 |
| | (13) | (17) | (1.9) | (0.46) | (14) | (3.3) |
| November 1986* | 131 | 80 | 4.3 | 1.3 | 34 | 6.4 |
| Coleoptera Larvae | | | | | | |
| November 1986 | 121 | 208 | 13 | 2.7 | 32 | 17 |
| | (30) | (53) | (5.6) | (1.1) | (13) | (6.9) |
| Araneida | | | | | | |
| May 1986 | 330 | 367 | 25 | 13 | 24 | 12 |
| | (99) | (160) | (33) | (3.0) | (4.7) | (3.1) |
| November 1986 | 326 | 442 | 9.2 | 8.7 | 37 | 12 |
| | (87) | (109) | (2.1) | (2.5) | (9.3) | (6.1) |
| Herbivorous Coleoptera | | | | | | |
| May 1986 | 211 | 84 | 9.3 | 1.6 | 37 | 25 |
| | (101) | (25) | (5.6) | (0.91) | (17) | (14) |

Mean values (n = 6) and standard deviations in parenthesis.
November 1986* Predatory Coleoptera - All specimens pooled from entire CDF.

3.3.4 Ottawa mine spoil reclamation site. Details of invertebrates collected in pitfall traps placed at the Ottawa site and metal concentrations measured in each of the taxonomic groups are given in Appendix D. Individuals of most of the major invertebrate taxa were present and their composition was similar to that recorded at Times Beach and Grand Island (Appendix A and B). Dredged material placed at the Ottawa site was from one source and metal concentrations (except Pb) in dredged material from plots 2-4 were not statistically different (Table 3) (Rhett & Richards, 1986). Insufficient data was available to make comparisons between the differently managed sub-plots and therefore mean metal concentrations measured in each of the taxonomic groups are presented (Table 12). In general, similar metal concentrations were measured in groups sampled in May and November (Table 12).

Table 12
Metal Concentrations in Soil Invertebrates Collected in Plots 2 - 4 at the Ottawa Mine Spoil Reclamation Site in Spring and Fall 1986.
All concentrations in ug/g, dry weight.

| Species/Sample | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Predatory Coleoptera | | | | | | |
| May 1986 | 101 | 17 | - | 0.85 | 6.2 | 8.6 |
| | (23) | (6.0) | | | (1.6) | (3.9) |
| November 1986 | 154 | 17 | 3.3 | 2.1 | 4.4 | 17 |
| | (71) | (1.5) | (1.9) | (2.0) | (2.8) | (7.2) |
| Araneida | | | | | | |
| May 1986 | 326 | 91 | 5.5 | 6.5 | 4.9 | 20 |
| | (48) | (31) | (4.9) | (1.5) | (1.5) | (11) |
| November 1986 | 263 | 112 | 2.6 | 6.4 | 6.7 | 10 |
| | (80) | (65) | (1.5) | (2.8) | (3.7) | (6.0) |
| Herbivorous Coleoptera | | | | | | |
| May 1986 | 145 | 31 | 11 | 1.3 | 7.5 | 30 |
| | (36) | (5.6) | (6.3) | (0.34) | (2.2) | (14) |
| November 1986 | s | s | s | s | s | s |
| Orthoptera | | | | | | |
| May 1986 | 183 | 47 | 2.1 | 1.4 | 1.4 | 8.0 |
| | (53) | (22) | (1.5) | (0.70) | (0.72) | (3.7) |
| November 1986 | 204 | 40 | 2.0 | 2.2 | 5.9 | 11 |
| | (56) | (14) | (1.0) | (1.3) | (4.7) | (8.3) |
| Lepidoptera L. | | | | | | |
| May 1986 | 159 | 25 | 1.9 | 1.6 | 4.0 | 9.0 |
| | (32) | (7.9) | (0.91) | (0.99) | (3.1) | (4.4) |
| November 1986 | s | s | s | s | s | s |
| Diplopoda | | | | | | |
| May 1986 | 393 | 98 | 6.2 | 2.0 | 4.1 | 25 |
| | (72) | (20) | (4.2) | (0.70) | (1.3) | (17) |
| November 1986 | 298 | 102 | 2.3 | 1.8 | 4.7 | 6.4 |
| | (119) | (26) | (2.0) | (1.4) | (3.1) | (4.3) |
| Isopoda | | | | | | |
| May 1986 | 582 | 219 | 6.5 | 8.0 | 9.0 | 33 |
| | (267) | (77) | (3.1) | (3.1) | (2.4) | (4.7) |
| November 1986 | 441 | 160 | 3.8 | 5.1 | 11 | 19 |
| | (76) | (25) | (2.9) | (1.7) | (5.9) | (7.4) |

Mean values and standard deviations in parenthesis.
s = insufficient sample size for analysis.

## 3.4 NATIVE EARTHWORMS.

Earthworms of the species Lumbricus terrestris; Allolobophora caliginosa; Allolobophora chlorotica and Lumbricus rubellus were present at the Times Beach CDF, Ottawa and Grand Island sites. At Times Beach, the deep burrowing species L. terrestris were found only in the higher, drier plots, where the top soil-like layer had developed to sufficient depth for burrowing. The lower, wetter plots were dominated by L. rubellus.

3.4.1 Times Beach CDF and Grand Island reference site. Earthworm species collected at both the Times Beach and Grand Island sites and metal concentrations in earthworm tissue are given in Appendix A, Tables 5 and 6 and Appendix B, Table 3. High concentrations of Zn and Cd were measured in all of the earthworm species collected. Inter-specific differences were clearly evident from the results, for example A. chlorotica contained lower concentrations of Zn compared with the remaining species. Within each species similar concentrations of each of the elements (except Cu) were present in the vegetation zones A, B and C at Times Beach (Table 13a). This agrees with measurements of metal concentrations in invertebrates collected in pitfall traps (Tables 10a-d) and results of laboratory uptake studies using E. foetida where no significant differences were noted in metal uptake between vegetation zones (Table 7a).

Table 13a
Comparative Metal Concentrations in Earthworms Collected from the Different Vegetation Zones at Times Beach.
Mean values expressed as ug/g, dry weight.

| Species/ Vegetation zone | Element Zn | Cu | Cd | Pb |
|---|---|---|---|---|
| L. rubellus | | | | |
| zone A | 1809[a] | 16[ab] | 57[a] | 0.34[a] |
| zone B | 1302[a] | 18[a] | 67[a] | 0.31[a] |
| zone C | 1332[a] | 11[b] | 58[a] | s |
| A. caliginosa | | | | |
| zone A | 1115[a]* | 26[a] | 27[a] | 1.2[a] |
| zone B | 1059[a]* | 21[ab] | 30[a] | 4.3[a] |
| zone C | 995[a]* | 16[b] | 37[a] | s |
| A. chlorotica | | | | |
| zone A | 412[a]* | 23[a] | 32[a]* | 5.9[a] |
| zone B | 467[a]* | 25[a] | 51[a]* | 8.9[a] |
| zone C | 417[a]* | 21[a] | 45[a]* | 3.6[a] |

a,b - means values in a column within each species followed by the same letter are not significantly different at $p < 0.05$.
* = Non-parametric statistical comparison of the means was employed.
s = insufficient sample size for statistical analysis.

Results for each species collected at Times Beach, were pooled and the mean value compared with the metal concentrations measured in each species collected at the Grand Island site (Table 13b). Generally, greater concentrations of Zn, Cu and Cd were present in earthworms collected at Times Beach compared with those collected at Grand Island. Cu concentrations in L. terrestris, Zn concentrations in A. chlorotica and Cd concentrations in

A. caliginosa were exceptions, similar concentrations were present in earthworms collected at each site. With the exception of Pb concentrations measured in L. rubellus, Pb concentrations were similar in earthworms collected at Times Beach and Grand Island indicating little difference in the bio-availability of this element between the two sites.

Table 13b
Comparative Metal Concentrations in Earthworms from Grand Island and Times Beach.
Mean values expressed in ug/g, dry weight.

| Species/ Site | Zn | Cu | Cd | Pb |
|---|---|---|---|---|
| L. terrestris | | | | |
| Times Beach | $2775^{a}$ | $16^{a*}$ | $48^{a}$ | $2.6^{a}$ |
| Grand Island$^{a1}$ | $350^{b}$ | $2.1^{a*}$ | $8.9^{b}$ | $4.0^{a}$ |
| L. rubellus | | | | |
| Times Beach | $1436^{a}$ | $16^{a}$ | $62^{a}$ | $1.5^{a}$ |
| Grand Island | $430^{b}$ | $4.6^{b}$ | $13^{b}$ | $0.32^{b}$ |
| A. caliginosa | | | | |
| Times Beach | $1064^{a}$ | $22^{a}$ | $34^{a}$ | $2.8^{a}$ |
| Grand Island | $479^{b}$ | $5.5^{b}$ | $31^{a}$ | $2.5^{a}$ |
| A. chlorotica | | | | |
| Times Beach | $434^{a*}$ | $23^{a}$ | $43^{a}$ | $7.0^{a}$ |
| Grand Island | $304^{a*}$ | $7.7^{b}$ | $18^{b}$ | $2.3^{a}$ |

a,b - means values in a column within each species followed by the same letter are not significantly different at $p < 0.05$.
* = Non-parametric statistical comparison of the means was employed.

3.4.2 Ottawa mine spoil reclamation site. Metal concentrations measured in native earthworms collected at the Ottawa mine spoil reclamation site are given in Appendix D, Table 3. UNusually dry conditions prevented collection of native earthworms by the formalin vermifuge method and these earthworms were collected incidentally in the pitfall traps. The use of these results for comparative purposes was limited since no correction to the metal concentrations was possible to eliminate the effect of soil within the gut.

## 3.5 COMPARATIVE METAL CONCENTRATIONS BETWEEN THE FOUR SITES.

For each of the elements Zn, Cu, Cd and Pb, metal concentrations in samples collected from the field sites are compared with the results of laboratory studies using E. foetida (Tables 14 - 17).

Table 14

Zinc Concentrations at the Four Sites.

| Sample | Unconsol. TB | Unconsol. BR | Times Beach TB-A | Times Beach TB-B | Times Beach TB-C | Grand Island | Ottawa OT-2 | Ottawa OT-3 | Ottawa OT-4 |
|---|---|---|---|---|---|---|---|---|---|
| DM/Soil | 2,002 | 1,413 | 289 | 480 | 426 | 227 | 1,003 | 1,008 | 1,043 |
| E. foetida | | | | | | | | | |
| Field uptake study: | | | | | | | | | |
| Lab. uptake study: | | | | | | | | | |
| Day 0 | 120 | 120 | 110 | 110 | 110 | 98 | | - | |
| Day 28 | 135 | 152 | litter:179 | 113 | 112 | | litter: | - | |
| Day 28 | | | humic:114 | 110 | 126 | 101 | 30cm: | - | |
| Day 28 | | | oxid.:112 | 115 | 114 | | 100cm: | - | |
| Invertebrates | | | | | | | | | |
| Pred. Coleoptera | | | | | | | | | |
| Spring'85 | | | 90 | 108 | 113 | | | | |
| Fall'85 | | | 99 | 111 | 104 | | | | |
| Spring'86 | | 80 | 147 | 109 | 105 | 102 | | 101 | |
| Fall'86 | | 131(121L.) | 114 | 100 | 90 | 63 | | 154 | |
| Araneida | | | | | | | | | |
| Spring'85 | | | 415 | 461 | 307 | | | | |
| Fall'85 | | | 166 | 140 | 142 | | | | |
| Spring'86 | | 330 | 325 | 311 | 299 | 238 | | 326 | |
| Fall'86 | | 326 | 213 | 215 | 209 | 194 | | 263 | |
| Herb. Coleoptera | | | | | | | | | |
| Spring'85 | | | - | - | - | | | | |
| Fall'85 | | | 222 | 153 | 167 | | | | |
| Spring'86 | | 211 | 127 | 204 | 190 | | | 145 | |
| Fall'86 | | | 222 | 171 | - | | | - | |
| Diplopoda | | | | | | | | | |
| Spring'85 | | | 211 | 242 | 174 | | | | |
| Fall'85 | | | 195 | 235 | 210 | | | | |
| Spring'86 | | | 269 | 227 | 254 | 198 | | 393 | |
| Fall'86 | | | 235 | 260 | 222 | 160 | | 298 | |
| Isopoda | | | | | | | | | |
| Spring'85 | | | 180 | 191 | 180 | | | | |
| Fall'85 | | | 314 | 326 | 281 | | | | |
| Spring'86 | | | 341 | 307 | 272 | 260 | | 582 | |
| Fall'86 | | | 234 | 297 | 332 | 219 | | 441 | |
| Native earthworms | | | | | | | | | |
| L. terrestris | | | 2,775 | | | 350 | | | |
| A. caliginosa | | | 1,115 | 1,059 | 995 | 479 | | | |
| A. chlorotica | | | 412 | 467 | 417 | 304 | | | |
| L.rubellus | | | 1,809 | 1,302 | 1,332 | 430 | | | |

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types: Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

Table 15
Copper Concentrations at the Four Sites.

| Sample | Unconsol. TB | Unconsol. BR | Times Beach TB-A | Times Beach TB-B | Times Beach TB-C | Grand Island | Ottawa OT-2 | Ottawa OT-3 | Ottawa OT-4 |
|---|---|---|---|---|---|---|---|---|---|
| DM/Soil | 432 | 2,606 | 51 | 95 | 83 | 68 | 85 | 95 | 96 |
| E. foetida | | | | | | | | | |
| Field uptake study: | | | | | | | | | |
| Lab. uptake study: | | | | | | | | | |
| Day 0 | 17 | 17 | 9.9 | 9.9 | 9.9 | 9.0 | | 9.6 | |
| Day 28 | 41 | 145 | litter: 15 | 12 | 12 | | litter: | 9.2 | |
| Day 28 | | | humic: 18 | 18 | 14 | 10 | 30cm: | 26 | |
| Day 28 | | | oxid: 29 | 23 | 24 | | 100cm: | 25 | |
| Invertebrates | | | | | | | | | |
| Pred. Coleoptera | | | | | | | | | |
| Spring'85 | | | 14 | 15 | 15 | | | | |
| Fall'85 | | | 18 | 19 | 16 | | | | |
| Spring'86 | | 64 | 18 | 18 | 19 | 15 | | 17 | |
| Fall'86 | | 80(208L.) | 31 | 18 | 19 | 16 | | 17 | |
| Araneida | | | | | | | | | |
| Spring'85 | | | 169 | 230 | 182 | | | | |
| Fall'85 | | | 111 | 77 | 103 | | | | |
| Spring'86 | | 367 | 230 | 177 | 114 | 202 | | 91 | |
| Fall'86 | | 442 | 85 | 78 | 64 | 64 | | 112 | |
| Herb. Coleoptera | | | | | | | | | |
| Spring'85 | | | - | - | - | | | | |
| Fall'85 | | | 42 | 35 | 26 | | | | |
| Spring'86 | | 84 | 33 | 34 | 33 | - | | 31 | |
| Fall'86 | | | 46 | 78 | - | - | | - | |
| Diplopoda | | | | | | | | | |
| Spring'85 | | | 641 | 660 | 634 | | | | |
| Fall'85 | | | 728 | 787 | 723 | | | | |
| Spring'86 | | | 683 | 681 | 755 | 218 | | 98 | |
| Fall'86 | | | 522 | 557 | 469 | 133 | | 102 | |
| Isopoda | | | | | | | | | |
| Spring'85 | | | 182 | 142 | 144 | | | | |
| Fall'85 | | | 310 | 223 | 208 | | | | |
| Spring'86 | | | 224 | 221 | 185 | 153 | | 219 | |
| Fall'86 | | | 130 | 101 | 186 | 79 | | 160 | |
| Native earthworms | | | | | | | | | |
| L. terrestris | | | 16 | | | 2.1 | | | |
| A. caliginosa | | | 26 | 21 | 16 | 5.5 | | | |
| A. chlorotica | | | 23 | 25 | 21 | 7.7 | | | |
| L.rubellus | | | 16 | 18 | 11 | 4.6 | | | |

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types: Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

Table 16

Cadmium Concentrations at the Four Sites.

| Sample | Unconsol. TB | Unconsol. BR | Times Beach TB-A | Times Beach TB-B | Times Beach TB-C | Grand Island | Ottawa OT-2 | Ottawa OT-3 | Ottawa OT-4 |
|---|---|---|---|---|---|---|---|---|---|
| DM/Soil | 13 | 21 | 3.3 | 6.4 | 5.0 | 2.5 | 6.9 | 7.4 | 7.8 |
| E. foetida | | | | | | | | | |
| Field uptake study: | | | | | | | | | |
| Lab. uptake study: | | | | | | | | | |
| Day 0 | 2.8 | 2.8 | 4.0 | 4.0 | 4.0 | 2.7 | | 3.7 | |
| Day 28 | 5.4 | 8.0 | litter:15 | 17 | 17 | | litter: | 14 | |
| Day 28 | | | humic:13 | 12 | 11 | 4.4 | 30cm: | 9.0 | |
| Day 28 | | | oxid: 6.1 | 6.4 | 7.3 | | 100cm: | 8.2 | |
| Invertebrates | | | | | | | | | |
| Pred. Coleoptera | | | | | | | | | |
| Spring'85 | | | 1.1 | 2.7 | 2.2 | | | | |
| Fall'85 | | | 2.1 | 2.6 | 1.6 | | | | |
| Spring'86 | | 1.1 | 4.7 | 4.4 | 3.5 | 2.0 | | 0.85 | |
| Fall'86 | | 1.3(2.7L.) | 2.7 | 2.7 | 2.5 | 1.1 | | 2.1 | |
| Araneida | | | | | | | | | |
| Spring'85 | | | 27 | 76 | 111 | | | | |
| Fall'85 | | | 15 | 8.8 | 18 | | | | |
| Spring'86 | | 13 | 71 | 36 | 29 | 13 | | 6.5 | |
| Fall'86 | | 8.7 | 8.6 | 14 | 7.3 | 3.9 | | 6.4 | |
| Herb. Coleoptera | | | | | | | | | |
| Spring'85 | | | - | - | - | | | | |
| Fall'85 | | | 0.99 | 0.69 | 0.72 | | | | |
| Spring'86 | | 1.6 | - | - | - | - | | 1.3 | |
| Fall'86 | | | 1.1 | 2.9 | - | - | | - | |
| Diplopoda | | | | | | | | | |
| Spring'85 | | | 2.8 | 3.7 | 2.2 | | | | |
| Fall'85 | | | 2.7 | 3.1 | 3.0 | | | | |
| Spring'86 | | | 3.9 | 4.0 | 4.1 | 2.7 | | 2.0 | |
| Fall'86 | | | 4.5 | 4.5 | 4.2 | 2.4 | | 1.8 | |
| Isopoda | | | | | | | | | |
| Spring'85 | | | 33 | 45 | 29 | | | | |
| Fall'85 | | | 23 | 22 | 23 | | | | |
| Spring'86 | | | 21 | 8 | 20 | 3.3 | | 8.0 | |
| Fall'86 | | | 30 | 27 | 23 | 8.2 | | 5.1 | |
| Native earthworms | | | | | | | | | |
| L. terrestris | | | 48 | | | 8.9 | | | |
| A. caliginosa | | | 27 | 30 | 37 | 31 | | | |
| A. chlorotica | | | 32 | 51 | 45 | 18 | | | |
| L. rubellus | | | 57 | 67 | 58 | 13 | | | |

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types: Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

Table 17
Lead Concentrations at the Four Sites.

| Sample | Unconsol. TB | Unconsol. BR | | Times Beach TB-A | Times Beach TB-B | Times Beach TB-C | Grand Island | | Ottawa OT-2 | Ottawa OT-3 | Ottawa OT-4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DM/Soil | 1,073 | 406 | | 161 | 212 | 172 | 44 | | 412 | 475 | 536 |
| E. foetida | | | | | | | | | | | |
| Field uptake study: | | | | | | | | | | | |
| Lab. uptake study: | | | | | | | | | | | |
| Day 0 | 2.7 | 2.7 | | <2.7 | <2.7 | <2.7 | <4.2 | | | 1.5 | |
| Day 28 | 13 | 4.5 | litter: | 5.5 | 2.7 | 3.5 | <2.7 | litter: | | 2.2 | |
| Day 28 | | | humic: | 9.1 | 4.9 | 6.4 | | 30cm: | | 2.9 | |
| Day 28 | | | oxid: | 8.7 | 9.7 | 11 | | 100cm: | | 5.3 | |
| Invertebrates | | | | | | | | | | | |
| Pred. Coleoptera | | | | | | | | | | | |
| Spring'85 | | | | 0.68 | 2.4 | 2.9 | | | | | |
| Fall'85 | | | | 7.1 | 5.0 | 4.5 | | | | | |
| Spring'86 | | 9.3 | | - | - | - | - | | | 8.6 | |
| Fall'86 | | 6.4(17L.) | | 2.5 | 5.0 | 7.1 | 3.8 | | | 17 | |
| Araneida | | | | | | | | | | | |
| Spring'85 | | | | 26 | 17 | 6.8 | | | | | |
| Fall'85 | | | | 9.0 | 14 | 8.5 | | | | | |
| Spring'86 | | 12 | | - | - | - | - | | | 20 | |
| Fall'86 | | 12 | | 6.7 | 7.2 | 6.6 | 17 | | | 10 | |
| Herb. Coleoptera | | | | | | | | | | | |
| Spring'85 | | | | - | - | - | | | | | |
| Fall'85 | | | | 13 | 13 | <7.9 | | | | | |
| Spring'86 | | 25 | | - | - | - | - | | | 30 | |
| Fall'86 | | | | <11 | <57 | - | - | | | - | |
| Diplopoda | | | | | | | | | | | |
| Spring'85 | | | | 7.5 | 6.1 | 5.8 | | | | | |
| Fall'85 | | | | 12 | 12 | 12 | | | | | |
| Spring'86 | | | | 22 | 16 | 14 | - | | | 25 | |
| Fall'86 | | | | 14 | 19 | 12 | 6.3 | | | 6.4 | |
| Isopoda | | | | | | | | | | | |
| Spring'85 | | | | 14 | 14 | 11 | | | | | |
| Fall'85 | | | | 17 | 16 | 13 | | | | | |
| Spring'86 | | | | 21 | - | 16 | 6.5 | | | 33 | |
| Fall'86 | | | | 18 | 17 | 17 | 14 | | | 19 | |
| Native earthworms | | | | | | | | | | | |
| L. terrestris | | | | 2.6 | | | 4.0 | | | | |
| A. caliginosa | | | | 1.2 | 4.3 | - | 2.5 | | | | |
| A. chlorotica | | | | 5.9 | 8.9 | 3.6 | 2.3 | | | | |
| L. rubellus | | | | 0.34 | 0.31 | - | 0.32 | | | | |

DM = Dredged Material; TB = Times Beach, A,B,C = Vegetation types: Times Beach
BR = Black Rock CDF; OT = Ottawa site, 2,3,4 = plots at the Ottawa site;
L. = Coleoptera larvae.

## 4. DISCUSSION.

### 4.1 COMPARISONS BETWEEN LABORATORY AND FIELD RESULTS.

#### 4.1.1 Unconsolidated dredged material: Times Beach CDF and Black Rock CDF.

Results of the laboratory uptake study indicated elevated concentrations of Zn, Cu, Ni, Cd, Cr and Pb in E. foetida after 28 days exposure to the dredged material (Table 5). Similar increases in concentrations of Zn and Ni were observed in earthworms exposed to Times Beach and Black Rock dredged materials. Concentrations of Cd, Cr and particularly Cu, suggested greater uptake from Black Rock compared with Times Beach dredged material, while Pb concentrations suggested greater uptake by earthworms exposed to the Times Beach dredged material (Table 5).

Comparisons of metal concentrations in invertebrates naturally colonizing the Times Beach and Black Rock CDF are limited due to the lack of detritivorous and soil inhabiting species at Black Rock. Zn concentrations in spiders (present at both sites in sufficient quantities for analysis) were within a similar range at Times Beach and Black Rock CDFs (Table 14) and Cu concentrations were greater in spiders collected at Black Rock compared with Times Beach (Table 15). For both elements the field situation reflected results of the laboratory uptake study. However, compared with Times Beach, Cd concentrations were lower in spiders from Black Rock (Table 16) and Pb concentrations were higher in spiders from Black Rock (Table 17), these results were contrary to those expected from the uptake study. Although earthworm uptake studies were conducted using unconsolidated dredged material considered to represent the original dredged material placed at the sites, the CDFs from which invertebrates were collected differed in age and degree of colonization by vegetation and this may have influenced the species compositions within the taxonomic groups. Differences in metal concentrations between species from the same site have previously been reported for Pb in spiders (Clausen, 1984), and metals in earthworms (Ireland, 1979, 1983, Ash & Lee, 1980). Metal concentrations measured in Isopoda collected at Times Beach in the present study also demonstrated the variation in metal concentrations between different genus of the same taxonomic group (Appendix E). This may explain the lack of correlation between laboratory and field results and further identification of individuals before analysis would be necessary to clarify this. Alternatively, since dredged materials are highly heterogenous, the single sample from each plot used in laboratory studies may have been inadequate to represent the whole site.

#### 4.1.2 Surface material: Times Beach CDF and Grand Island reference site.

Results of the laboratory uptake study using soil from Grand Island were compared with results of uptake by E. foetida exposed to dredged material from the humic layer at Times Beach (level 1, Tables 6 & 7). Very little uptake of Zn was observed over the 28 day period by earthworms exposed to either materials (Table 14). After 28 days, Cu concentrations were greater in E. foetida exposed to Times Beach dredged material compared with Grand Island soil (Table 15). Earthworms at the start of both studies contained similar concentrations of Cu but not Cd, those worms used for the Times Beach study had lower Cd concentrations compared with those used in the Grand Island study (Table 16). However, after 28 days, there was proportionally greater uptake of Cd by earthworms in the Times Beach dredged material (3 x the initial concentration) compared with the Grand Island soil (2 x the initial concentration) suggesting higher bio-availability of Cd in the Times Beach material (Table 16). Results suggested some uptake of Pb by E. foetida from the Times Beach but not the Grand Island material (Table 17). In summary, results of the laboratory study suggested greater bio-availability of Cu, Cd and Pb but not Zn at Times Beach compared with Grand Island.

Comparisons between metal concentrations measured in invertebrates collected at the Times Beach CDF and Grand Island reference site (Tables 10c & 10d, Table 13b) indicated a similar range in Zn concentrations in the Coleoptera, Araneida, Diplopoda and Isopoda. However, the native earthworms from Times Beach had consistently higher Zn concentrations compared with those from Grand Island. Diplopoda and native earthworms had greater Cu concentrations at Times Beach compared with Grand Island. Cd concentrations in the Araneida (Fall 1986), Isopoda and native earthworms (except A. caliginosa) were lower at Grand Island compared with Times Beach. Pb concentrations in the invertebrates were generally within a similar range at the two sites (Table 17).

Results of the laboratory study were supported by measurements in the field as follows: The laboratory study indicated very little uptake of Zn by E. foetida, from both Times Beach dredged material and Grand Island soil. Zn concentrations measured in invertebrates collected at the two field sites were not statistically different, with the exception of Zn concentrations measured in the native earthworm species (L. terrestris, A. caliginosa and L. rubellus, Table 13b) and in Coleoptera collected in spring 1986 (Table 10c). The laboratory uptake study suggested higher bio-availability of Cu, Cd and Pb from the Times Beach dredged material than the Grand Island soil. In the field, greater concentrations of both Cu and Cd were evident in at least one group of organisms at the Times Beach CDF compared with the Grand Island site. Native earthworms contained significantly higher concentrations of both Cu and Cd at Times Beach compared with Grand Island (Table 13b). Some bioavailability of Pb from the Times Beach dredged material but not the Grand Island soil was indicated by the results of the laboratory uptake study. However, measurements of invertebrates, including native earthworms, collected in the field showed no significant difference in Pb concentrations at Times Beach CDF compared with Grand Island reference site with the exception of Diplopoda collected in fall 1986 (Table 10d) and the earthworm species L. rubellus (Table 13b). In general, results suggested that the earthworms did provide a good indication of the 'worst case' for uptake of the elements Zn, Cu, Cd and Pb at each of the sites studied.

Differences in metal concentrations between native earthworm species may be a reflection of feeding preferences and of variation in the bioavailability of metals present in the different horizons of the substrate. Of the earthworms species collected, A. caliginosa predominantly ingests mineral soil, burrowing within the mineral soil horizons, while the other three species either predominantly inhabit the litter layer (L. rubellus and A. chlorotica) or feed mainly on leaf litter (L. terrestris). Results of the laboratory uptake study using E. foetida demonstrated significant differences in the availability of metals with changing depth within the dredged material (Table 7b). Cadmium concentrations were significantly greater in litter dwelling and litter feeding earthworm species at Times Beach compared with Grand Island while there was no significant difference between the two sites in Cd concentrations in A. caliginosa (Table 13b). This may indicate that Cd more bio-available in the litter layer compared with the lower horizons.

Results of the laboratory uptake study (Table 7b) also demonstrate an decrease in uptake of Cd with increasing depth in the dredged material.

4.1.3 Ottawa mine spoil reclamation site. General comparisons between the results of earthworm uptake studies using dredged material (depth 30 cm) from Ottawa and those from Times Beach and Grand Island suggested greater bioavailability of Cu in the Ottawa material, similar bioavailability of Cd compared with Times Beach and less available Pb compared with Times Beach but not Grand Island (Tables 15 - 17). The general pattern observed in invertebrates collected at Ottawa did not correspond with these results. Cu concentrations in invertebrates from Ottawa were within a similar range to those from Times Beach and Grand Island and Cu concentrations in the Diplopoda were lower at Ottawa compared with Times Beach and Grand Island (Table 15). Cd concentrations were lower in invertebrates from Ottawa (Table 16) and Pb concentrations were higher in invertebrates from Ottawa (Table 17) compared with the other sites. These were contrary to the expected results based on the laboratory study. Further standardization of the laboratory earthworm bioassay procedure measuring metal uptake may be necessary before valid comparisons can be made between tests. E. foetida used in the studies may need to be more standardized in terms of age and previous exposure to contaminants (i.e. all grown in the same substrate with careful separation of cocoons to maintain groups of the same age). Both factors have been demonstrated to influence metal uptake by Annelids (Bryan & Hummerstone, 1973, Ma, 1982a). In addition, soil physical properties have been shown to affect metal uptake by earthworms (Ma, 1982a) and it may be necessary to more closely define the physical and chemical properties of the dredged material. Repeatability of the laboratory procedure could be checked by using a standard reference substrate for which the earthworms response is known.

4.2 TARGET ORGANISMS FOR METAL UPTAKE.

Any taxonomic group to be used as an indicator of heavy metal mobility in the upland zone of confined disposal sites such as those studied here must fulfill certain requirements:-

(i) It must be easily collected in sufficient quantities both numerically and in terms of dry matter biomass across the range of vegetation types and soil moisture conditions at the sites for chemical analysis.

(ii) Results of analysis of tissue heavy metal concentrations should reflect the maximum bioavailability of heavy metals to that trophic level.

Invertebrate fauna collected in the pitfall traps placed at the Times Beach CDF and Grand Island reference site were dominated both numerically and in terms of dry matter contribution to the total biomass by Coleoptera, Diplopoda and Isopoda (Appendix A, Tables 1c, 2c, 3b & 4b, Appendix B, Tables 1b & 2b), and at the Ottawa mine spoil reclamation site by these groups as well as Orthoptera (Appendix D, Table 1c). At Black Rock Harbor CDF the Araneida and Coleoptera dominated the composition of the pitfall trap collections (Appendix C, Table 1c). These groups were present in all vegetation types across the sites. Dominance of these active groups reflects the sampling technique, collecting species seeking prey and detritivores moving in the litter and at the soil surface.

Generally, smallest metal concentrations were evident in the herbivorous species. Of the predatory species, Coleoptera showed little evidence of metal uptake and the Araneida reflected maximum uptake of metals at the carnivore trophic level, suggesting some movement of metals up the food chain (Tables 14 - 17). Wade et al. (1980) measuring Pb and Zn concentrations in invertebrates at increasing distances from a major road also recorded higher Pb concentrations in Arachnida compared with Carabidae. Seasonal differences recorded in the metal concentrations of Araneida reduce their usefulness as an indicator group and further investigations are required to clarify the reasons for this variability.

For each of the sites, greatest metal concentrations were measured in detritivorous species including native earthworms. Soils and associated decomposing matter have been recognised as the ultimate sink for metal contaminants present present in the ecosystem (Martin et al., 1982). Therefore metal concentrations in the detritivorous organisms should provide most relevant information for movement of metals into the food chain. Of the detritivores collected the Diplopoda, Isopoda and native earthworms were sufficiently abundant for chemical analysis at all sites except Black Rock CDF. Isopoda have been shown to accumulate Zn, Cu, Cd and Pb from their food to a greater extent than other terrestrial arthropods (Weiser et al., 1976, Coughtrey et al., 1977) and have been proposed as an ideal indicator of the bio-availability of these elements from the leaf litter which comprises their diet (Hopkin and Martin, 1982). Earthworms are also useful as indicators of heavy metal bio-availability since they are present in most soils, are intimately in contact with the soil and decomposing material and form a vital link in many food chains. They represent the site from which they were collected because they are relatively sedentary and they almost always provide sufficient material for analysis (Ma, 1982b, Diercxsens et al., 1985). Compared with the other soil dwelling invertebrates collected at the four sites, the native earthworms contained the greatest Zn concentrations. Cu concentrations were greater in the Diplopoda and Cd concentrations were similar between the earthworms and the Isopoda. Pb concentrations were within a similar range in the earthworms as in the other invertebrate fauna collected in the pitfall traps.

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## APPENDICES

Appendix A **TIMES BEACH CDF.**

Surface active invertebrates collected at the Times Beach CDF in spring and fall (1985 and 1986) were identified, and a record of the relative abundance calculated. Where sufficient material was available metal analysis was carried out.

TABLE 1 MAY 1985

TABLE 1(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

| PLOT | COL. | ARAN. | CHIL. | DIPL. | ISOP. | OTHERS |
|---|---|---|---|---|---|---|
| A1 | 9 | 4 | 3 | 23 | 148 | 2 Oligochaeta/2 Orthoptera/1 Diptera<br>2 Hymenoptera/1 Coleoptera L. |
| A4 | 9 | 3 | 3 | 29 | 120 | 10 Oligochaeta/5 Coleoptera L. |
| B4 | 26 | 11 | 1 | 19 | 244 | 4 Oligochaeta/3 Coleoptera L.<br>3 Hymenoptera/3 Thysanoptera/1Diptera |
| B5 | 10 | 2 | 2 | 19 | 183 | 17 Oligochaeta/5 Coleoptera L. |
| C1 | 23 | 8 | - | 11 | 44 | 2 Diptera/1 Acarina<br>1 Thysanoptera/2 Hymenoptera |
| C2 | 8 | 2 | - | 8 | 124 | 6 Oligochaeta/2 Acarina<br>2 Hemiptera |
| C4 | 51 | 6 | - | 6 | 19 | 1 Oligochaeta/2 Hymenoptera/<br>2 Hemiptera/1 Lepidoptera L. |

TABLE 1(b) Identification of major groups of soil dwelling invertebrate fauna collected in pitfall traps. MAY 1985

1. COLEOPTERA

| PLOT | SUB-ORDER | FAMILY | GENUS | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|---|
| A1 | Geodephaga | Carabidae | Carabus sp | 2 |
| | Geodephaga | Carabidae | Pterostichus sp | 1 |
| | Sternoxia | Elatiderae | Agriotes sp | 1 |
| | Rhynchophora | Curculionidae Otiorrhynchinae | | 2 |
| | Rhynchophora | Curculionidae | | 1 |
| | Brachelytra | Staphylinidae | | 1 |
| | Geodephaga | Carabidae | Bradycellus sp | 1 |
| A4 | Geodephaga | Carabidae | Carabus sp | 8 |
| | Geodephaga | Carabidae | Pterostichus sp | 1 |
| | Brachelytra | Staphylinidae Tachyporidae | Tachyporus sp | 1 |
| | Rhynchophora | Curculionidae Otiorrhynchinae | Barypithes sp? | 1 |
| B4 | Geodephaga | Carabidae | Carabus sp | 2 |
| | Geodephaga | Carabidae | Chlaenius sp | 2 |
| | Geodephaga | Carabidae | Pterostichus sp | 17 |
| | Lamellicornia | Scarabidae | | 1 |
| | Brachelytra | Staphylinidae | Staphylinius sp | 1 |
| | Brachelytra | Staphylinidae Tachyporinae | Tachyporus sp | 2 |
| B5 | Geodephaga | Carabidae | Carabus sp | 4 |
| | Geodephaga | Carabidae | Pterostichus sp | 5 |
| | Lamellicornia | Trogidae | Trox sp | 2 |

TABLE 1(b) contd...

| PLOT | SUB-ORDER | FAMILY | GENUS | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|---|
| C1 | Geodephaga | Carabidae | Chlaenius sp | 10 |
| | Geodephaga | Carabidae | Pterostichus sp | 10 |
| | Sternoxia | Elatiderae | Agriotes | 1 |
| | Brachelytra | Staphylinidae | | |
| | | Oxytelinidae | | 1 |
| C2 | Geodephaga | Carabidae | Carabus | 1 |
| | Geodephaga | Carabidae | Pterostichus sp | 1 |
| | Brachelytra | Staphylinidae | | |
| | | Tachyporidae | | 1 |
| | Geodephaga | Carabidae | Chlaenius sp | 2 |
| | Brachelytra | Staphylinidae | | |
| | | Oxytelinidae | | 1 |
| | Clavicornia | Nitidulidae | | |
| | | Nitidulinae | | 2 |
| C4 | Geodephaga | Carabidae | Chlaenius sp | 19 |
| | Geodephaga | Carabidae | Pterostichus sp | 9 |
| | Geodephaga | Carabidae | Bembidion sp | 2 |
| | Geodephaga | Carabidae | Agonum sp | 2 |
| | Clavicornia | Nitidulidae | | |
| | | Nitidulinae | | 1 |
| | Brachelytra | Staphylinidae | | 17 |

2. All Araneida identified as belonging to the Family Agriopoidea.

3. All Chilopoda identified as belonging to the Family Scutigeridae.

TABLE 1(b) contd...

4. DIPLOPODA

| PLOT | FAMILY | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|
| A1 | Blaniulidae | 20 |
| | Polydesmidae | 3 |
| A4 | Blaniulidae | 29 |
| | Polydesmidae | 4 |
| B4 | Blaniulidae | 14 |
| | Polydesmidae | 6 |
| B5 | Blaniulidae | 17 |
| | Polydesmidae | 4 |
| C1 | Blaniulidae | 12 |
| C2 | Blaniulidae | 8 |
| C4 | Blaniulidae | 6 |

TABLE 1(b) contd...

5. ISOPODA

| PLOT | FAMILY | ABUNDANCE * least common<br>**** most common |
|---|---|---|
| A1 | Porcellionidae | *** |
| | Trichoniscidae | **** |
| | Oniscidae | ** |
| A4 | Porcellionidae | *** |
| | Oniscidae | ** |
| | Trichoniscidae | **** |
| | Armadillidiidae | * |
| B4 | Porcellionidae | *** |
| | Trichoniscidae | **** |
| | Oniscidae | ** |
| B5 | Porcellionidae | *** |
| | Trichoniscidae | **** |
| C1 | Porcellionidae | *** |
| | Trichoniscidae | **** |
| | Oniscidae | ** |
| C2 | Porcellionidae | *** |
| | Trichoniscidae | **** |
| | Oniscidae | ** |
| C4 | Porcellionidae | *** |
| | Trichoniscidae | **** |

TABLE 1 contd...

TABLE 1(c) Composition of soil dwelling invertebrate fauna sampled using pitfall traps over a three day period at Times Beach. Total dry matter (g) and relative percentage dry matter (%) of four pooled samples per plot. MAY 1985.

| PLOT | PRED. COL. | ARAN. | CHIL. | DIPL. | ISOP. | OTHERS |
|---|---|---|---|---|---|---|
| A1 (g) | 0.3479 | 0.0060 | 0.0700 | 0.1063 | 0.2774 | 0.12 |
| (%) | 37.26 | 0.64 | 7.51 | 11.41 | 29.77 | 13.40 |
| A4 (g) | 1.5008 | 0.0091 | 0.0615 | 0.1995 | 0.2500 | 0.14 |
| (%) | 69.50 | 0.42 | 2.85 | 9.24 | 11.58 | 6.41 |
| B4 (g) | 0.9868 | 0.0391 | 0.0187 | 0.1345 | 0.1988 | 1.74 |
| (%) | 31.65 | 1.25 | 0.60 | 4.31 | 6.38 | 55.81 |
| B5 (g) | 0.9064 | 0.0045 | 0.0531 | 0.2237 | 0.1331 | 0.26 |
| (%) | 57.36 | 0.28 | 3.36 | 14.16 | 8.42 | 16.42 |
| C1 (g) | 0.5727 | 0.0170 | - | 0.1053 | 0.0626 | 0.01 |
| (%) | 48.74 | 1.45 | - | 9.01 | 5.33 | 0.85 |
| C2 (g) | 0.2547 | 0.0125 | - | 0.029 | 0.1049 | 0.05 |
| (%) | 24.25 | 1.19 | - | 9.01 | 5.33 | 0.85 |
| C4 (g) | 1.0407 | 0.1063 | - | 0.054 | 0.0395 | - |
| (%) | 83.22 | 8.50 | - | 4.32 | 3.16 | - |

TABLE 1 contd...

TABLE 1(d) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). MAY 1985

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 92 | 14 | <0.43 | 0.85 | 2.6 | <1.5 |
| A4 | 87 | 14 | <0.35 | 1.3 | 1.7 | <1.2 |
| B4 | 115 | 16 | 1.1 | 2.6 | 5.5 | 4.2 |
| B5 | 100 | 13 | <0.34 | 2.8 | 1.7 | <1.2 |
| C1 | 114 | 17 | 0.74 | 2.1 | 4.7 | 5.1 |
| C2 | 108 | 11 | <0.59 | 1.9 | 3.0 | <2.1 |
| C4 | 118 | 18 | <0.72 | 2.6 | 3.5 | 2.6 |

(2) ARANEIDA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 369 | 165 | <13 | 28 | 117 | <44 |
| A4 | 461 | 172 | <8.3 | 26 | 52 | 30 |
| B4 | 411 | 253 | <1.9 | 112 | 14 | <6.8 |
| B5 | 511 | 207 | 17 | 40 | 85 | <59 |
| C1 | 336 | 182 | <4.5 | 114 | 30 | <16 |
| C2 | 342 | 190 | <6.1 | 148 | 37 | <21 |
| C4 | 244 | 174 | <0.71 | 70 | 6.1 | <2.5 |

(3) CHILOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 279 | 60 | <1.1 | 6.0 | 6.8 | <3.8 |
| A4 | 283 | 57 | <1.2 | 12 | 7.3 | <4.3 |
| B4 | 193 | 45 | <4.0 | 25 | 22 | <14 |
| B5 | 272 | 28 | <1.4 | 4.2 | 8.9 | <5.0 |

TABLE 1(d) contd...

DETRITIVOROUS SPECIES

(4) DIPLOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 228 | 630 | <2.5 | 2.9 | 5.8 | 10.4 |
| A4 | 194 | 652 | <1.5 | 2.6 | 4.3 | <9.7 |
| B4 | 280 | 693 | 1.9 | 3.5 | 8.7 | 7.9 |
| B5 | 204 | 626 | <1.7 | 3.8 | 4.2 | <8.4 |
| C1 | 158 | 581 | 1.0 | 1.8 | 5.8 | 6.2 |
| C2 | 178 | 731 | <2.6 | 2.4 | 9.2 | <9.2 |
| C4 | 187 | 591 | <1.4 | 2.3 | 7.1 | 6.6 |

(5) ISOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 195 | 192 | 3.5 | 31 | 13 | 13 |
| A4 | 164 | 171 | 2.9 | 35 | 7.6 | 14 |
| B4 | 209 | 157 | 2.3 | 41 | 14 | 13 |
| B5 | 173 | 127 | 3.9 | 49 | 11 | 14 |
| C1 | 113 | 110 | 2.4 | 21 | 9.3 | 12 |
| C2 | 179 | 149 | 2.9 | 45 | 12 | 16 |
| C4 | 249 | 173 | <1.9 | 21 | 15 | <6.7 |

TABLE 2 OCTOBER 1985

TABLE 2(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

| PLOT | COL. | ARAN. | CHIL. | DIPL. | ISOP. | ORTH. | OTHERS |
|---|---|---|---|---|---|---|---|
| A1 | 20 | 18 | 3 | 26 | 196 | 5 | 5 Diptera/1 Dermaptera/1 Mollusc 4 Hemiptera/15 Hymenoptera 7 Neuroptera/2 Lepidoptera/1 Olig. |
| A2 | 14 | 11 | 2 | 20 | 118 | 7 | 1 Acarina/1 Diptera/2 Hemiptera/ 22 Hymenoptera/1 Mollusca 1 Oligochaeta |
| A3 | 5 | 5 | 2 | 31 | 102 | 7 | 2 Acarina/4 Diptera/37 Hymenoptera 1 Neuroptera/2 Oligochaeta |
| A4 | 19 | 35 | 8 | 49 | 161 | 28 | 7 Acarina/4 Diptera/1 Hemiptera 27 Hymenoptera/1 Mollusca/ 6 Oligochaeta |
| B1 | 23 | 29 | 1 | 12 | 261 | 10 | 7 Acarina/1 Diptera/2 Hemiptera 8 Hymenoptera/2 Mollusca 2 Oligochaeta |
| B2 | 29 | 51 | 2 | 5 | 121 | 34 | 6 Acarina/2 Dermaptera/2 Diptera 6 Hemiptera/8 Hymenoptera |
| B3 | 23 | 32 | 5 | 60 | 211 | 8 | 4 Acarina/10 Hymenoptera 1 Oligochaeta |
| B4 | 15 | 36 | 2 | 33 | 105 | 9 | 5 Acarina/5 Hemiptera/ 13 Hymenoptera/2 Lepidoptera 3 Oligochaeta |
| B5 | 26 | 25 | 2 | 17 | 54 | 14 | 4 Acarina/1 Dermaptera/5 Hemiptera 16 Hymenoptera/1 Thysanoptera 8 Oligochaeta |
| C1 | 69 | 33 | 1 | 7 | 301 | 62 | 6 Acarina/3 Diptera/1 Hemiptera 14 Hymenoptera/1 Mollusca 5 Oligochaeta |
| C2 | 107 | 28 | 5 | 16 | 243 | 58 | 15 Acarina/1 Dermaptera/4 Diptera 20 Hymenoptera/2 Neuroptera/ 5 Oligochaeta |
| C3 | 31 | 33 | 5 | 27 | 181 | 28 | 5 Acarina/4 Diptera/15 Hymenoptera 1 Lepidoptera/2 Mollusca 1 Oligochaeta |
| C4 | 16 | 38 | 6 | 6 | 142 | 17 | 10 Acarina/2 Diptera/1 Hemiptera 18 Hymenoptera/1 Mollusca 5 Oligochaeta |

TABLE 2 contd...

TABLE 2(b) Identification of major groups of soil dwelling invertebrate fauna. OCTOBER 1985

1. COLEOPTERA

| PLOT | SUB-ORDER | FAMILY | GENUS | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|---|
| A1 | Geodephaga | Carabidae | Amara sp | 12 |
| | Lamellicornia | Trogidae | Trox sp | 2 |
| | Rhynchophora | Curculionidae | | 1 |
| | Rhynchophora | Otiorynchinae | | 1 |
| | Clavicornia | Nitidulidae | | 2 |
| | Lamellicornia | Scarabidae | Aphodius? | 1 |
| | Brachelytra | Staphylinidae | Tachyporus sp | 1 |
| A2 | Geodephaga | Carabidae | Pterostichus | 2 |
| | Geodephaga | Carabidae | Amara | 5 |
| | Clavicornia | Nitidulinidae | ? | 3 |
| | Rhynchophora | Curculionidae | ? | 4 |
| A3 | Geodephaga | Carabidae | Calathus sp | 1 |
| | Geodephaga | Carabidae | Amara sp | 1 |
| | Clavicornia | Nitidulinidae | ? | 1 |
| | Rhynchophora | Curculionidae | ? | 2 |
| A4 | Geodephaga | Carabidae | Carabus sp | 1 |
| | Geodephaga | Carabidae | Pterostichus sp | 1 |
| | Geodephaga | Carabidae | Amara sp | 10 |
| | Geodephaga | Carabidae | Harpalus sp | 1 |
| | Geodephaga | Carabidae | Bembidion sp | 1 |
| | Geodephaga | Carabidae | | 1 |
| | Lamellicornia | Trogidae | Trox sp | 1 |
| | Rhynchophora | Curculionidae | | 3 |

TABLE 2(b) contd...

| PLOT | SUB-ORDER | FAMILY | GENUS | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|---|
| B1 | Geodephaga | Carabidae | Pterostichus sp | 5 |
| | Geodephaga | Carabidae | Harpalus sp | 1 |
| | Geodephaga | Carabidae | Amara sp | 12 |
| | Geodephaga | Carabidae | Clivina? sp | 1 |
| | Geodephaga | Carabidae | | 1 |
| | Rhynchophora | Curculionidae | | 2 |
| | Brachelytra | Staphylinidae | Aleocharinae | 1 |
| B2 | Geodephaga | Carabidae | Carabus sp | 1 |
| | Geodephaga | Carabidae | Amara sp | 15 |
| | Geodephaga | Carabidae | Pterostichus | 1 |
| | Geodephaga | Carabidae | | 3 |
| | Clavicornia | Nitidulinidae | | 1 |
| | Rhynchophora | Curculionidae | | 1 |
| | ? | Chrysomelidae | Altica? | 3 |
| | Brachelytra | Staphylinidae | Aleocharinae | 2 |
| | Brachelytra | Staphylinidae | Omaliinae | 1 |
| | Brachelytra | Staphylinidae | Staphylininae | 1 |
| B3 | Geodephaga | Carabidae | Carabus sp | 1 |
| | Geodephaga | Carabidae | Amara sp | 15 |
| | Geodephaga | Carabidae | Pterostichus | 1 |
| | Geodephaga | Carabidae | ? | 3 |
| | Clavicornia | Nitidulinidae | ? | 1 |
| | Rhynchophora | Curculionidae | ? | 1 |
| | ? | Chrysomelidae | Altica? | 3 |
| | Brachelytra | Staphylinidae | Aleocharine | 2 |
| | Brachelytra | Staphylinidae | Omaliinae | 1 |
| | Brachelytra | Staphylinidae | Staphylininae | 1 |
| B4 | Geodephaga | Carabidae | Amara sp | 11 |
| | Lamellicornia | Trogidae | Trox sp | 1 |
| | Brachelytra | Staphylinidae | Tachyporus sp | 1 |
| | Clavicornia | Nitidulinidae | ? | 2 |
| B5 | Geodephaga | Carabidae | Amara sp | 19 |
| | Lamellicornia | Trogidae | Trox sp | 1 |
| | Clavicornia | Nitidulidae | | 1 |
| | Brachelytra | Staphylinidae | Aleocharinae | 1 |
| | Brachelytra | Staphylinidae | Tachyporus sp | 1 |
| | Brachelytra | Staphylinidae | Omaliniiae | 2 |
| | Brachelytra | Staphylinidae | | 1 |

TABLE 2(b) contd...

| PLOT | SUB-ORDER | FAMILY | GENUS | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|---|
| C1 | Geodephaga | Carabidae | Carabus sp | 1 |
| | Geodephaga | Carabidae | Amara sp | 57 |
| | Geodephaga | Carabidae | Pterostichus sp | 3 |
| | Geodephaga | Carabidae | Agonum | 1 |
| | Geodephaga | Carabidae | Clivina sp | 1 |
| | Geodephaga | Carabidae | ? | 2 |
| | Clavicornia | Nitidulidae | ? | 1 |
| | ? | Chrysomelidae | ? | 1 |
| | Brachelytra | Staphylinidae | Tachyporus sp | 2 |
| C2 | Geodephaga | Carabidae | Carabus | 1 |
| | Geodephaga | Carabidae | Amara | 76 |
| | Geodephaga | Carabidae | Pterostichus | 14 |
| | Geodephaga | Carabidae | ? | 1 |
| | Clavicornia | Nitidulidae | ? | 1 |
| | Lamellicornia | Trogidae | Trox sp | 2 |
| | Rhynchophora | Curculionidae | ? | 2 |
| | Geodephaga | Carabidae | Bembidion sp | 1 |
| | Brachelytra | Staphylinidae | Omaliniinae | 1 |
| | Brachelytra | Staphlyinidae | Tachyporus sp | 2 |
| | Brachelytra | Staphylinidae | Aleocharinae | 4 |
| | ? | Chrysomelidae | Halticinae | 2 |
| C3 | Geodephaga | Carabidae | Amara sp | 7 |
| | Geodephaga | Carabidae | Pterostichus sp | 1 |
| | Geodephaga | Carabidae | ? | 6 |
| | | Otiorynchinae | ? | 1 |
| | Clavicornia | Nitidulidae | ? | 4 |
| | Geodephaga | Carabidae | Bembidion sp | 2 |
| | Brachelytra | Staphylinidae | Tachyporus sp | 6 |
| | Brachelytra | Staphylinidae | Aleocharine | 2 |
| | ? | Chrysomelidae | ? | 1 |
| | ? | | | 1 |
| C4 | Geodephaga | Carabidae | Amara sp | 3 |
| | Geodephaga | Carabidae | Pterostichus sp | 1 |
| | Geodephaga | Carabidae | Agonus sp | 2 |
| | Geodephaga | Carabidae | Harpulus sp | 2 |
| | Geodephaga | Carabidae | ? | 3 |
| | Clavicornia | Nitidulidae | ? | 1 |
| | Brachelytra | Staphylinidae | Omaliniiae | 3 |
| | Brachelytra | Staphylinidae | Tachyporus sp | 1 |
| | Brachelytra | Staphylinidae | Philonthius sp | 1 |
| | Brachelytra | Staphylinidae | Aleocharinae | 1 |

TABLE 2(b) contd...

4. DIPLOPODA

| PLOT | FAMILY | GENUS | SPECIES | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|---|
| A1 | Blaniulidae | Isobates | littoralis | 6 |
| | Blaniulidae | Choneiulus | palmatus | 19 |
| | Polydesmidae | Brachydesmus | sp | 1 |
| A2 | Blaniulidae | Isobates | littoralis | 7 |
| | Blaniulidae | Choneiulus | palmatus | 13 |
| A3 | Blaniulidae | Isobates | littoralis | 7 |
| | Blaniulidae | Choneiulus | palmatus | 23 |
| | Polydesmidae | Brachydesmus | sp | 1 |
| A4 | Blaniulidae | Isobates | littoralis | 13 |
| | Blaniulidae | Choneiulus | palmatus | 24 |
| | Polydesmidae | Brachydesmus | sp | 12 |
| B1 | Blaniulidae | Isobates | littoralis | 3 |
| | Blaniulidae | Choneiulus | palmatus | 9 |
| B2 | Blaniulidae | Choneiulus | littoralis | 4 |
| | Polydesmidae | Brachydesmus | sp | 1 |
| B3 | Blaniulidae | Isobates | littoralis | 17 |
| | Blaniulidae | Choneiulus | palmatus | 40 |
| | Polydesmidae | Brachydesmus | sp | 3 |
| B4 | Blaniulidae | Isobates | littoralis | 20 |
| | Polydesmidae | Brachydesmus | sp | 13 |
| B5 | Blaniulidae | Choneiulus | palmatus | 17 |
| C1 | Blaniulidae | Isobates | littoralis | 1 |
| | Blaniulidae | Choneiulus | palmatus | 6 |
| C2 | Blaniulidae | Isobates | littoralis | 3 |
| | Blaniulidae | Choneiulus | palmatus | 9 |
| | Polydesmidae | Brachydesmus | sp | 12 |
| C3 | Blaniulidae | Isobates | littoralis | 1 |
| | Blaniulidae | Choneiulus | palmatus | 6 |
| C4 | Blaniulidae | Choneiulus | palmatus | 6 |

TABLE 2(b) contd...

5. ISOPODA

| PLOT | FAMILY | GENUS | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|
| A1 | Oniscidae | Oniscus | 44 |
| | Porcellionidae | Porcellio | 98 |
| | Trichoniscidae | Trichoniscus | 48 |
| | Armadillidiidae | Armadillidium | 6 |
| A2 | Oniscidae | Oniscus | 17 |
| | Porcellionidae | Porcellio | 72 |
| | Trichoniscidae | Trichoniscus | 16 |
| | Armadillidiidae | Armadillidium | 13 |
| A3 | Oniscidae | Oniscus | 3 |
| | Porcellionidae | Porcellio | 67 |
| | Trichoniscidae | Trichoniscus | 6 |
| | Armadillidiidae | Armadillidium | 26 |
| A4 | Oniscidae | Oniscus | 10 |
| | Porcellionidae | Porcellio | 74 |
| | Trichoniscidae | Trichoniscus | 65 |
| | Armadillidiidae | Armadillidium | 12 |
| B1 | Oniscidae | Oniscus | 3 |
| | Porcellionidae | Porcellio | 46 |
| | Trichoniscidae | Trichoniscus | 211 |
| | Armadillidiidae | Armadillidium | 1 |
| B2 | Oniscidae | Oniscus | 3 |
| | Porcellionidae | Porcellio | 36 |
| | Trichoniscidae | Trichoniscus | 81 |
| | Armadillidiidae | Armadillidium | 1 |
| B3 | Oniscidae | Oniscus | 1 |
| | Porcellionidae | Porcellio | 40 |
| | Trichoniscidae | Trichoniscus | 169 |
| | Armadillidiidae | Armadillidium | 1 |
| B4 | Oniscidae | Oniscus | 11 |
| | Porcellionidae | Porcellio | 36 |
| | Trichoniscidae | Trichoniscus | 57 |
| | Armadillidiidae | Armadillidium | 1 |
| B5 | Oniscidae | Oniscus | 2 |
| | Porcellionidae | Porcellio | 23 |
| | Trichoniscidae | Trichoniscus | 29 |
| | Armadillidiidae | Armadillidium | 0 |

TABLE 2(b) contd...

| PLOT | FAMILY | GENUS | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|
| C1 | Oniscidae | _Oniscus_ | 1 |
| | Porcellionidae | _Porcellio_ | 25 |
| | Trichoniscidae | _Trichoniscus_ | 274 |
| | Armadillidiidae | _Armadillidium_ | 1 |
| C2 | Oniscidae | _Oniscus_ | 15 |
| | Porcellionidae | _Porcellio_ | 80 |
| | Trichoniscidae | _Trichoniscus_ | 147 |
| | Armadillidiidae | _Armadillidium_ | 0 |
| C3 | Oniscidae | _Oniscus_ | 1 |
| | Porcellionidae | _Porcellio_ | 40 |
| | Trichoniscidae | _Trichoniscus_ | 140 |
| | Armadillidiidae | _Armadillidium_ | 0 |
| C4 | Oniscidae | _Oniscus_ | 0 |
| | Porcellionidae | _Porcellio_ | 27 |
| | Trichoniscidae | _Trichoniscus_ | 115 |
| | Armadillidiidae | _Armadillidium_ | 0 |

6. ORTHOPTERA

| PLOT | FAMILY | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|
| A1 | Tettigoniidae | 5 |
| A2 | Tettigoniidae | 7 |
| A3 | Tettigoniidae | 7 |
| A4 | Tettigoniidae | 28 |
| B1 | Tettigoniidae | 10 |
| B2 | Tettigoniidae | 34 |
| B3 | Tettigoniidae | 8 |
| B4 | Tettigoniidae | 9 |
| B5 | Tettigoniidae | 14 |
| C1 | Tettigoniidae | 61 |
| | Acrididae | 1 |
| C2 | Tettigoniidae | 58 |
| C3 | Tettigoniidae | 28 |
| C4 | Tettigoniidae | 17 |

TABLE 2 contd...

TABLE 2(c) Composition of soil dwelling invertebrate fauna sampled by pitfall traps over a ten day period at Times Beach. Total dry matter (g) and relative percentage dry matter contribution (%) of four pooled samples per plot. OCTOBER 1985

| PLOT | | PRED. COL. | ARAN. | OPIO. | CHIL. | HERB. COL. | ORTH. | DIPL. | ISOP. | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|
| A1 | (g) | 0.068 | 0.016 | 0.055 | 0.035 | 0.028 | 0.069 | 0.126 | 1.343 | 0.054 |
| | (%) | 3.8 | 0.89 | 3.1 | 2.0 | 1.6 | 3.8 | 7.0 | 74.9 | 3.0 |
| A2 | (g) | 0.102 | 0.094 | 0.073 | 0.019 | 0.008 | 0.089 | 0.108 | 0.873 | 0.034 |
| | (%) | 7.3 | 6.7 | 5.2 | 1.4 | 0.57 | 6.4 | 7.7 | 62.4 | 2.4 |
| A3 | (g) | 0.008 | 0.113 | 0.030 | 0.001 | 0.003 | 0.092 | 0.135 | 0.673 | 0.038 |
| | (%) | 0.73 | 10.3 | 2.7 | 0.09 | 0.27 | 8.4 | 12.4 | 61.6 | 3.5 |
| A4 | (g) | 0.373 | 0.013 | 0.177 | 0.029 | 0.020 | 0.273 | 0.705 | 0.221 | 0.197 |
| | (%) | 18.6 | 0.6 | 8.8 | 1.4 | 1.0 | 13.6 | 35.1 | 11.0 | 9.8 |
| B1 | (g) | 0.401 | 0.006 | 0.095 | 0.002 | 0.005 | 0.128 | 0.102 | 0.441 | 0.029 |
| | (%) | 33.2 | 0.50 | 7.9 | 0.17 | 0.41 | 10.6 | 8.4 | 36.5 | 2.4 |
| B2 | (g) | 0.543 | 0.011 | 0.113 | 0.027 | 0.005 | 0.342 | 0.040 | 0.334 | 0.078 |
| | (%) | 36.4 | 0.74 | 7.6 | 1.8 | 0.33 | 22.9 | 2.7 | 22.4 | 5.2 |
| B3 | (g) | 0.314 | 0.005 | 0.107 | 0.084 | 0.003 | 0.077 | 0.285 | 0.444 | 0.093 |
| | (%) | 2.2 | 0.35 | 7.5 | 5.9 | 0.21 | 0.50 | 20.2 | 31.4 | 6.6 |
| B4 | (g) | 0.108 | 0.040 | 0.120 | 0.005 | 0.003 | 0.062 | 0.165 | 0.363 | 0.070 |
| | (%) | 11.5 | 4.3 | 12.8 | 0.5 | 0.3 | 6.6 | 0.2 | 38.8 | 7.5 |
| B5 | (g) | 0.343 | 0.030 | 0.092 | 0.017 | 0.009 | 0.163 | 0.142 | 0.178 | 0.104 |
| | (%) | 31.8 | 2.8 | 8.5 | 1.6 | 0.8 | 15.1 | 13.2 | 16.5 | 9.6 |
| C1 | (g) | 1.270 | 0.071 | 0.086 | 0.002 | 0.001 | 0.867 | 0.117 | 0.478 | 0.278 |
| | (%) | 40.1 | 2.2 | 2.7 | 0.63 | 0.03 | 27.4 | 3.7 | 15.1 | 8.8 |
| C2 | (g) | 2.222 | 0.038 | 0.134 | 0.111 | 0.034 | 0.690 | 0.107 | 0.772 | 0.154 |
| | (%) | 52.1 | 0.9 | 3.1 | 2.6 | 0.8 | 16.2 | 2.5 | 18.1 | 3.6 |
| C3 | (g) | 0.153 | 0.071 | 0.086 | 0.037 | 0.034 | 0.308 | 0.207 | 0.337 | 0.061 |
| | (%) | 11.86 | 5.5 | 6.6 | 2.9 | 2.6 | 23.8 | 16.0 | 26.0 | 4.7 |
| C4 | (g) | 0.185 | 0.089 | 0.062 | 0.026 | <0.001 | 0.164 | 0.052 | 0.333 | 0.082 |
| | (%) | 18.6 | 9.0 | 6.2 | 2.6 | - | 16.5 | 5.2 | 33.5 | 8.3 |

TABLE 2 contd...

TABLE 2(d) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). OCTOBER 1985

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 77 | 15 | <1.1 | 0.56 | 6.1 | <3.9 |
| A2 | 104 | 22 | 1.4 | 4.0 | 10 | 9.5 |
| A3 | - | - | - | - | - | - |
| A4 | 117 | 16 | 1.1 | 1.6 | 6.6 | 9.7 |
| B1 | 103 | 17 | 1.3 | 2.6 | 4.1 | 5.3 |
| B2 | 103 | 16 | <0.69 | 1.0 | 4.1 | 5.2 |
| B3 | 143 | 21 | 0.87 | 4.0 | 3.1 | 4.0 |
| B4 | 122 | 21 | 1.8 | 4.5 | 8.6 | 7.0 |
| B5 | 82 | 18 | 0.48 | 0.82 | 2.3 | 3.2 |
| C1 | 108 | 15 | 0.97 | 1.6 | 2.4 | 2.6 |
| C2 | 123 | 18 | 1.4 | 2.3 | 2.4 | 2.9 |
| C3 | 108 | 16 | 1.9 | 1.7 | 7.7 | 8.2 |
| C4 | 76 | 14 | 2.7 | 0.89 | 8.4 | 4.2 |

(2) ARANEIDA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 166 | 111 | 18 | 15 | - | 9.0 |
| Veg. B | 140 | 77 | 4.8 | 8.8 | 11 | 14 |
| Veg. C | 142 | 103 | 2.4 | 18 | 21 | 8.5 |

(3) OPIOLONES

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 165 | 37 | 1.9 | 14 | 3.9 | 8.5 |
| Veg. B | 121 | 38 | 2.1 | 12 | 2.6 | 8.6 |
| Veg. C | 132 | 39 | 1.5 | 16 | 4.2 | 8.1 |

TABLE 2(d) contd.. .

(4) CHILOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 152 | 48 | 32 | 4.2 | 3.5 | <2.9 |
| Veg. B | 152 | 37 | 3.8 | 3.5 | 8.5 | 9.1 |
| Veg. C | 138 | 30 | 2.1 | 5.0 | 1.3 | <7.9 |

HERBIVOROUS SPECIES

(5) Herbivorous COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 222 | 42 | 3.1 | 0.99 | 19 | 13 |
| Veg. B | 153 | 35 | 2.2 | 0.69 | 11 | 13 |
| Veg. C | 167 | 26 | 3.6 | 0.72 | 22 | <7.9 |

(6) ORTHOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 175 | 31 | 2.3 | 12 | 7.4 | 11 |
| A2 | 217 | 36 | 4.4 | 9.8 | 9.9 | 16 |
| A3 | 182 | 45 | 6.7 | 11 | 8.6 | 15 |
| A4 | 186 | 34 | 3.3 | 6.8 | 7.9 | 17 |
| B1 | 164 | 28 | 3.7 | 17 | 7.3 | 10 |
| B2 | 192 | 31 | 2.5 | 14 | 5.0 | 8.9 |
| B3 | 168 | 35 | 3.3 | 9.1 | 8.1 | 14 |
| B4 | 155 | 30 | 2.5 | 5.5 | 12 | 11 |
| B5 | 150 | 23 | 1.7 | 10 | 3.3 | 5.6 |
| C1 | 229 | 28 | 2.0 | 12 | 1.9 | 5.2 |
| C2 | 250 | 32 | 5.2 | 11 | 2.8 | 6.3 |
| C3 | 183 | 33 | 3.9 | 6.8 | 14 | 9.4 |
| C4 | 120 | 19 | 2.2 | 8.6 | 3.0 | 6.6 |

TABLE 2(d) contd...

DETRITIVOROUS SPECIES

(7) DIPLOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 186 | 784 | 2.7 | 2.8 | 6.6 | 12 |
| A2 | 176 | 706 | 2.7 | 2.3 | 6.6 | 12 |
| A3 | 188 | 662 | 1.8 | 2.3 | 6.9 | 11 |
| A4 | 229 | 760 | 1.7 | 3.2 | 3.5 | 11 |
| B1 | 222 | 632 | 2.1 | 2.8 | 8.5 | 13 |
| B2 | 243 | 839 | <1.8 | 2.8 | 12 | 10 |
| B3 | 248 | 901 | 2.9 | 3.5 | 6.1 | 16 |
| B4 | 244 | 765 | 2.9 | 3.2 | 6.3 | 11 |
| B5 | 216 | 798 | 2.2 | 3.4 | 5.2 | 12 |
| C1 | 124 | 494 | 1.3 | 1.9 | 4.0 | 8.0 |
| C2 | 248 | 718 | 2.5 | 2.8 | 7.1 | 12 |
| C3 | 252 | 962 | 3.6 | 4.0 | 7.8 | 17 |
| C4 | 217 | 716 | <1.4 | 3.3 | 7.9 | 9.1 |

(8) ISOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 243 | 328 | 2.1 | 33 | 7.8 | 16 |
| A2 | 291 | 305 | 3.8 | 22 | 14 | 20 |
| A3 | 373 | 285 | 2.4 | 14 | 7.9 | 15 |
| A4 | 349 | 320 | 2.8 | 24 | 10 | 16 |
| B1 | 402 | 239 | 4.3 | 23 | 15 | 21 |
| B2 | 291 | 198 | 3.3 | 21 | 11 | 16 |
| B3 | 283 | 201 | 3.5 | 27 | 9 | 20 |
| B4 | 318 | 261 | 2.4 | 21 | 6.9 | 12 |
| B5 | 335 | 216 | 4.4 | 19 | 6.2 | 11 |
| C1 | 274 | 136 | 1.6 | 22 | 6.8 | 9.0 |
| C2 | 292 | 263 | 2.1 | 29 | 11 | 12 |
| C3 | 286 | 226 | 3.5 | 20 | 13 | 19 |
| C4 | 270 | 206 | 2.2 | 19 | 6.7 | 10 |

TABLE 3. MAY 1986

TABLE 3(a) Record of numbers of soil dwelling invertebrates collected in four pitfall traps per plot.

| PLOT | COL. | ARAN. | CHIL. | DIP. | ISOP. | OTHERS |
|---|---|---|---|---|---|---|
| A1 | 9 | 2 | 5 | 98 | 17 | 1 Homoptera/5 Hymenoptera/1 Diptera 1 Mollusca |
| A2 | 48 | 3 | 2 | 53 | 17 | 3 Hymenoptera/1 Acarina |
| A3 | 20 | 5 | 1 | 11 | 11 | 6 Hymenoptera/2 Diptera/5 Acarina 1 Lepidoptera |
| A4 | 14 | 6 | - | 59 | 10 | 3 Hymenoptera/3 Acarina/1 Neuroptera 1 Orthoptera |
| B1 | 39 | 6 | - | 20 | 5 | 1 Orthoptera/1 Oligochaeta |
| B2 | 13 | 7 | - | 34 | 14 | 3 Hymenoptera/1 Diptera |
| B3 | 3 | 2 | 1 | 39 | 13 | 1 Hymenoptera/2 Hemiptera |
| B4 | 42 | 15 | 3 | 14 | 28 | 8 Hymenoptera/4 Acarina/1 Orthoptera |
| B5 | 32 | 12 | 1 | 48 | 12 | 3 Hymenoptera/4 Acarina 1 Oligochaeta |
| C1 | 59 | 7 | 5 | 14 | 2 | 1 Acarina/1 Orthoptera/2 Oligochaeta |
| C2 | 11 | 7 | 3 | 65 | 124 | 1 Hymenoptera/2 Oligochaeta |
| C3 | 42 | 18 | - | 12 | 1 | 1 Hymenoptera/7 Diptera/2 Acarina 1 Hemiptera/2 Orthoptera/1 Olig. |
| C4 | 43 | 8 | 2 | 30 | 37 | 6 Hymenoptera/5 Diptera/3 Acarina |

TABLE 3 contd...

TABLE 3(b) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a ten day period at Times Beach. Total dry matter (g) and percentage dry matter contribution (%) four pooled samples per plot. MAY 1986

| PLOT | | PRED. COL. | ARANEIDA | CHILOPODA | HERB. COL. | DIPLOPODA | ISOPODA | OTHERS |
|---|---|---|---|---|---|---|---|---|
| A1 | (g) | 1.056 | - | 0.010 | 0.002 | 0.371 | 0.128 | 0.024 |
| | (%) | 66.4 | - | 0.06 | 0.10 | 23.3 | 8.0 | 1.5 |
| A2 | (g) | 4.369 | 0.018 | - | - | 0.234 | 0.069 | 0.004 |
| | (%) | 93.5 | 0.4 | - | - | 4.7 | 1.4 | 0.1 |
| A3 | (g) | 0.222 | 0.001 | - | 0.014 | 0.031 | 0.046 | 0.239 |
| | (%) | 40.1 | 0.2 | - | 2.5 | 5.6 | 8.3 | 43.2 |
| A4 | (g) | 0.706 | 0.002 | - | 0.003 | 0.247 | 0.036 | 0.018 |
| | (%) | 69.8 | 0.2 | - | 0.3 | 24.4 | 3.6 | 1.8 |
| B1 | (g) | 0.578 | 0.049 | - | - | 0.122 | 0.022 | 0.153 |
| | (%) | 62.6 | 5.3 | - | - | 13.2 | 2.4 | 16.6 |
| B2 | (g) | 0.188 | 0.097 | - | - | 0.168 | 0.052 | 0.002 |
| | (%) | 37.1 | 19.1 | - | - | 33.1 | 10.3 | 0.4 |
| B3 | (g) | 0.018 | 0.005 | - | - | 0.161 | 0.015 | 0.001 |
| | (%) | 9.0 | 2.5 | - | - | 80.5 | 7.5 | 0.5 |
| B4 | (g) | 0.439 | 0.008 | 0.002 | 0.025 | 0.080 | 0.060 | 0.028 |
| | (%) | 66.3 | 1.2 | 3.3 | 3.8 | 12.1 | 9.1 | 4.2 |
| B5 | (g) | 0.620 | 0.125 | 0.001 | 0.003 | 0.212 | 0.046 | 0.071 |
| | (%) | 57.5 | 11.6 | 0.1 | 0.3 | 19.6 | 4.3 | 6.6 |
| C1 | (g) | 1.056 | - | 0.010 | 0.002 | 0.371 | 0.128 | 0.024 |
| | (%) | 66.4 | - | 0.6 | 0.1 | 23.3 | 8.0 | 1.5 |
| C2 | (g) | 0.131 | 0.029 | 0.076 | 0.041 | 0.274 | 0.235 | 0.011 |
| | (%) | 16.4 | 3.6 | 9.5 | 5.1 | 34.4 | 29.5 | 1.4 |
| C3 | (g) | 0.159 | 0.030 | 0.141 | - | 0.069 | 0.019 | 0.060 |
| | (%) | 61.9 | 3.6 | 16.8 | - | 8.2 | 2.3 | 7.2 |
| C4 | (g) | 0.314 | 0.020 | 0.048 | 0.008 | 0.445 | 0.116 | 0.047 |
| | (%) | 48.7 | 3.1 | 7.4 | 1.2 | 21.9 | 16.0 | 1.7 |

TABLE 3 contd...

TABLE 3(c) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g. dry weight). MAY 1986

*CARNIVOROUS SPECIES*

(1) Predatory COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 148 | 19 | - | 2.0 | 4.3 | - |
| A2 | 140 | 19 | - | 7.1 | 1.4 | - |
| A3 | 149 | 18 | - | 3.5 | 2.0 | - |
| A4 | 151 | 16 | - | 6.1 | - | - |
| B1 | 123 | 15 | - | 3.8 | 4.0 | - |
| B2 | 83 | 14 | - | 3.2 | 2.2 | - |
| B3 | | | | | | |
| B4 | 112 | 22 | - | 4.1 | 3.4 | - |
| B5 | 119 | 19 | - | 6.6 | - | - |
| C1 | 120 | 21 | - | 3.4 | 4.3 | - |
| C2 | 84 | 15 | - | 1.0 | 2.0 | - |
| C3 | 109 | 21 | - | 5.0 | 6.5 | - |
| C4 | 106 | 18 | - | 4.6 | 2.9 | - |

(2) ARANEIDA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 325 | 230 | - | 71 | 5.9 | - |
| Veg. B | 311 | 177 | 23 | 36 | 4.6 | - |
| Veg. C | 299 | 114 | 10 | 29 | 5.3 | - |

(3) CHILOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 818 | 67 | - | - | - | - |
| Veg. B | 193 | 47 | - | 9.0 | - | - |
| Veg. C | 212 | 50 | 12 | 5.2 | 2.9 | - |

TABLE 3(c) contd...

HERBIVOROUS SPECIES

(4) Herbivorous COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 127 | 33 | - | - | - | - |
| Veg. B | 204 | 34 | - | - | - | - |
| Veg. C | 190 | 33 | - | - | 7.7 | - |

(5) ORTHOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| All plots. | 188 | 56 | - | 3.2 | 7.0 | 8.3 |

TABLE 3(c) contd...

DETRITIVOROUS SPECIES

(6) DIPLOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 213 | 839 | 3.3 | 3.9 | 6.2 | 15 |
| A2 | 393 | 551 | - | 2.2 | 8.3 | 29 |
| A3 | 304 | 639 | - | 5.4 | 5.2 | - |
| A4 | 167 | 702 | - | 4.1 | 3.8 | - |
| B1 | 266 | 689 | - | 6.9 | 6.9 | 23 |
| B2 | 218 | 851 | 3.3 | 3.1 | 5.6 | 18 |
| B3 | 176 | 556 | 4.4 | 2.8 | 5.3 | 15 |
| B4 | 242 | 683 | 4.3 | 3.3 | 5.1 | 14 |
| B5 | 235 | 628 | 3.0 | 3.9 | 3.7 | 12 |
| C1 | 323 | 876 | - | 5.0 | 8.4 | - |
| C2 | 238 | 705 | 4.2 | 3.7 | 5.0 | - |
| C3 | 241 | 756 | - | 4.5 | 6.3 | - |
| C4 | 214 | 683 | 4.3 | 3.3 | 5.1 | 14 |

(7) ISOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 226 | 242 | 4.3 | 20 | 5.5 | 15 |
| A2 | 501 | 223 | 7.6 | 27 | 12 | 26 |
| A3 | 374 | 243 | - | 11 | 7.2 | - |
| A4 | 263 | 186 | - | 27 | 5.8 | - |
| B1 | 251 | 189 | - | 17 | 7.8 | - |
| B2 | 343 | 194 | - | 14 | 11 | - |
| B3 | 326 | 295 | - | 22 | 19 | - |
| B4 | 290 | 237 | - | 29 | 7.6 | - |
| B5 | 323 | 192 | - | 24 | 6.6 | - |
| C1 & 3 | 421 | 221 | - | 11 | 12 | - |
| C2 | 167 | 142 | 16 | 28 | 6.1 | - |
| C4 | 232 | 192 | 7.1 | 20 | 6.1 | 16 |

TABLE 4 NOVEMBER 1986

TABLE 4(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

| PLOT | COL. | ARAN. | OPIO. | CHIL. | DIPL. | ISOP. | ORTH. | OTHERS |
|---|---|---|---|---|---|---|---|---|
| A1 | 9 | 8 | 5 | 1 | 11 | 43 | - | 12 Diptera/ 3 Hemiptera<br>1 Mollusca/ 2 Hymenoptera |
| A2 | 14 | 21 | 3 | - | 19 | 84 | - | 13 Diptera/21 Hymenoptera<br>4 Dermaptera/3 Hemiptera<br>4 Acarina/1 Mollusc/10lig |
| A3 | 6 | 12 | 18 | 6 | 62 | 421 | 2 | 12 Diptera/1 Hemiptera<br>9 Hymenoptera/3 Mollusca<br>9 Oligochaeta |
| A4 | 9 | 4 | 3 | 3 | 34 | 62 | - | 4 Diptera/1 Hemiptera<br>1 Mollusca/1 Hymenoptera<br>6 Oligochaeta |
| B1 | 12 | 11 | 1 | 1 | 4 | 5 | 1 | 6 Diptera/4 Hymenoptera<br>8 Mollusca |
| B2 | 12 | 19 | 4 | 1 | 4 | 6 | 1 | 9 Diptera/2 Hymenoptera<br>15 Mollusca/4 Hemiptera |
| B3 | 9 | 14 | 11 | 1 | 13 | 94 | 4 | 9 Diptera/1 Hemiptera<br>2 Neuroptera/1 Mollusca |
| B4 | 10 | 14 | 3 | 2 | 5 | 11 | 3 | 4 Diptera/8 Hymenoptera<br>37 Mollusca/1 Acarina<br>1 Oligochaeta |
| B5 | 12 | 5 | 8 | 1 | 2 | 260 | 1 | 6 Diptera/9 Hymenoptera<br>7 Mollusca/1 Oligochaeta |
| C1 | 7 | 18 | 2 | - | 2 | 20 | - | 2 Diptera/4 Mollusca<br>1 Oligochaeta |
| C2 | 16 | 16 | 4 | - | 7 | 82 | 5 | 12 Diptera/1 Hymenoptera<br>4 Dermaptera/4 Mollusca |
| C3 | 13 | 26 | 2 | - | 2 | 3 | 7 | 19 Diptera/1 Hymenoptera<br>2 Mollusca/1 Lepidoptera |
| C4 | 15 | 25 | 2 | 1 | 2 | 2 | 2 | 9 Diptera/1 Hymenoptera<br>1 Hemiptera/1 Acarina<br>1 Mollusca/1 Lepidoptera |

TABLE 4 contd...

TABLE 4(b) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a ten day period at Times Beach. Total dry matter (g) and percentage dry matter contribution (%), four samples per plot. NOVEMBER 1986.

| PLOT | | PRED. COL. | ARAN. | OPIO. | CHIL. | HERB. COL. | DIPL. | ISOP. | ORTH. | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|
| A1 | (g) | 0.289 | 0.011 | 0.036 | 0.001 | - | 0.013 | 0.119 | - | 0.090 |
| | (%) | 51.69 | 1.97 | 6.44 | 0.18 | - | 2.33 | 21.29 | - | 16.10 |
| A2 | (g) | 0.253 | 0.025 | 0.013 | 0.112 | 0.006 | 0.061 | 0.232 | - | 0.190 |
| | (%) | 28.36 | 2.80 | 1.46 | 12.56 | 0.67 | 6.84 | 26.01 | - | 21.30 |
| A3 | (g) | 0.066 | 0.021 | 0.110 | 0.029 | 0.001 | 0.169 | 0.303 | 0.021 | 0.110 |
| | (%) | 7.95 | 2.53 | 13.25 | 3.49 | 0.12 | 20.36 | 36.51 | 2.53 | 13.25 |
| A4 | (g) | 0.109 | 0.006 | 0.025 | 0.109 | 0.016 | 0.004 | 0.561 | - | 0.210 |
| | (%) | 10.48 | 0.58 | 2.40 | 10.48 | 1.54 | 0.38 | 53.94 | - | 20.19 |
| B1 | (g) | 0.074 | 0.037 | 0.009 | 0.024 | 0.001 | 0.009 | 0.004 | 0.016 | 0.020 |
| | (%) | 38.14 | 19.07 | 4.64 | 12.37 | 0.52 | 4.64 | 2.06 | 8.25 | 10.31 |
| B2 | (g) | 0.044 | 0.076 | 0.026 | 0.003 | 0.004 | 0.007 | 0.016 | 0.016 | 0.020 |
| | (%) | 20.75 | 35.85 | 12.26 | 1.42 | 1.89 | 3.30 | 7.55 | 7.55 | 9.43 |
| B3 | (g) | 0.112 | 0.038 | 0.088 | 0.001 | - | 0.031 | 0.100 | 0.038 | 0.030 |
| | (%) | 25.57 | 8.68 | 20.09 | 0.23 | - | 7.08 | 22.83 | 8.68 | 6.85 |
| B4 | (g) | 0.121 | 0.009 | 0.016 | 0.004 | 0.001 | 0.020 | 0.017 | 0.044 | 0.140 |
| | (%) | 32.53 | 2.42 | 4.30 | 1.08 | 0.27 | 5.38 | 4.57 | 11.83 | 37.63 |
| B5 | (g) | 0.108 | 0.009 | 0.044 | 0.005 | - | 0.053 | 0.230 | 0.011 | 0.080 |
| | (%) | 20.00 | 1.67 | 8.15 | 0.93 | - | 9.81 | 42.59 | 2.04 | 14.81 |
| C1 | (g) | 0.038 | 0.084 | 0.017 | - | - | 0.016 | 0.037 | - | 0.270 |
| | (%) | 8.23 | 18.18 | 3.68 | - | - | 3.46 | 8.01 | - | 58.44 |
| C2 | (g) | 0.202 | 0.031 | 0.017 | - | - | 0.044 | 0.058 | 0.075 | 0.160 |
| | (%) | 34.41 | 5.28 | 2.89 | - | - | 7.49 | 9.88 | 12.78 | 27.26 |
| C3 | (g) | 0.072 | 0.099 | 0.017 | - | - | 0.005 | 0.003 | 0.087 | 0.130 |
| | (%) | 17.43 | 23.97 | 4.12 | - | - | 1.21 | 0.73 | 21.07 | 31.47 |
| C4 | (g) | 0.147 | 0.124 | 0.021 | - | - | 0.029 | 0.016 | 0.027 | 0.150 |
| | (%) | 28.59 | 24.12 | 4.09 | - | - | 5.64 | 3.11 | 5.25 | 29.18 |

TABLE 4 contd...

TABLE 4(c) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). NOVEMBER 1986

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 179 | 54 | 3.0 | 4.9 | 2.4 | 2.4 |
| A2 | 120 | 36 | 1.3 | - | 7.5 | 2.4 |
| A3 | 78 | 17 | 1.4 | 1.1 | 8.9 | <4.0 |
| A4 | 80 | 17 | 2.3 | 2.1 | 5.6 | 3.1 |
| B1 | 96 | 22 | 4.1 | 1.5 | 7.6 | 10 |
| B2 | 139 | 20 | 4.6 | 4.3 | 4.3 | <6.0 |
| B3 | 86 | 16 | 2.3 | 2.4 | 2.3 | 5.8 |
| B4 | 85 | 14 | 1.4 | 2.4 | 2.7 | 2.2 |
| B5 | 95 | 16 | 3.3 | 3.0 | 4.4 | 4.1 |
| C1 | 98 | 23 | 5.2 | 1.9 | 6.5 | 14 |
| C2 | 86 | 17 | 2.5 | 3.0 | 1.0 | 4.2 |
| C3 | 82 | 16 | 2.9 | 2.0 | 6.4 | 5.0 |
| C4 | 94 | 20 | 5.5 | 3.2 | 6.4 | 5.0 |

(2) ARANEIDA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 & A4 | 221 | 82 | 7.2 | 8.8 | 8.1 | <16 |
| A2 | 231 | 93 | 4.9 | 8.0 | 2.8 | <11 |
| A3 | 188 | 79 | 5.4 | 9.0 | 7.0 | <13 |
| B1 | 207 | 89 | 5.1 | 18 | 6.5 | 9.5 |
| B2 | 193 | 60 | 1.5 | 14 | <0.26 | 3.8 |
| B3 | 213 | 74 | 9.2 | 7.1 | 0.56 | 8.0 |
| B4 & B5 | 248 | 90 | <4.4 | 15 | 4.1 | <15 |
| C1 | 215 | 57 | 3.0 | 7.2 | 7.2 | 14 |
| C2 | 208 | 71 | <2.4 | 7.1 | 5.3 | <8.6 |
| C3 | 205 | 67 | 1.4 | 8.2 | 1.9 | 4.6 |
| C4 | 208 | 59 | 2.5 | 6.8 | 3.7 | 3.6 |

TABLE 4(c) contd...

(3) OPIOLONES

| ZONE | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 526 | 53 | 5.4 | 31 | 15 | 7.1 |
| Veg. B | 483 | 44 | 3.9 | 28 | 4.2 | 11 |
| Veg. C | 414 | 33 | 18 | 17 | 11 | 18 |

(4) CHILOPODA

| ZONE | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 281 | 40 | 6.9 | 3.3 | 2.5 | 2.8 |
| Veg. B | 454 | 121 | 33 | 8.6 | 16 | 18 |
| Veg. C | | | Insufficient sample | | | |

HERBIVOROUS SPECIES

(5) Herbivorous COLEOPTERA

| ZONE | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Veg. A | 222 | 46 | 7.9 | 1.1 | 18 | <11 |
| Veg. B | 171 | 78 | 35 | 2.9 | 76 | <57 |
| Veg. C | | | Insufficient sample | | | |

(6) ORTHOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1, A2 & A4 | | | Insufficient sample | | | |
| A3 | 122 | 32 | 9.5 | 6.5 | - | <13 |
| B1 & B2 | 174 | 35 | 8.1 | 9.5 | 16 | 16 |
| B3 | 143 | 32 | 5.6 | 4.1 | 6.0 | 11 |
| B4 & B5 | 154 | 23 | 7.1 | 8.4 | 5.4 | 9.7 |
| C1 | | | Insufficient sample | | | |
| C2 | 133 | 22 | 3.2 | 9.2 | 4.1 | 9.7 |
| C3 | 141 | 23 | 2.8 | 4.7 | 2.1 | 7.6 |
| C4 | 146 | 34 | 8.1 | 4.4 | 8.8 | 12 |

TABLE 4(d) contd...

DETRITIVOROUS SPECIES

(7) DIPLOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 & A4 | 236 | 461 | 12 | 4.8 | 6.8 | 16 |
| A2 | 267 | 611 | 10.4 | 4.9 | 5.2 | 11 |
| A3 | 201 | 586 | 7.0 | 3.8 | 5.9 | 14 |
| B1 & B2 | 335 | 711 | 29 | 5.8 | 18 | 22 |
| B3 | 291 | 555 | 19 | 4.7 | 11 | 21 |
| B4 & B5 | 154 | 405 | 6.0 | 3.1 | 5.0 | 13 |
| C1.C3 & C4 | 270 | 518 | 8.0 | 5.0 | 10.1 | 13 |
| C2 | 174 | 419 | 8.1 | 3.3 | 5.0 | 10 |

(8) ISOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 229 | 110 | 5.2 | 24 | 6.4 | 17 |
| A2 | 305 | 150 | 4.1 | 24 | 5.3 | 16 |
| A3 | 235 | 118 | 3.7 | 37 | 4.6 | 24 |
| A4 | 166 | 142 | 3.3 | 35 | 3.0 | 13 |
| B1 & B2 | 320 | 106 | 18 | 16 | 12 | 25 |
| B3 | 290 | 124 | 5.9 | 18 | 6.2 | 16 |
| B4 | 369 | 84 | 20 | 31 | 17 | <15 |
| B5 | 207 | 89 | 5.6 | 41 | 6.8 | 18 |
| C1 | 235 | 148 | 5.4 | 25 | 6.9 | 16 |
| C2 | 280 | 96 | 6.4 | 28 | 7.0 | 17 |
| C3 & C4 | 481 | 314 | 16 | 15 | 10.3 | 19 |

TABLE 5 MAY 1985

**Native earthworms**.
Metal concentrations measured in the native earthworms collected using formalin vermifuge from the defined vegetation zones at Times Beach. All *concentrations expressed as* ug/g, dry weight.

TABLE 5 Native earthworms collected at Times Beach. MAY 1985
All species, from each plot pooled for analysis and no correction made for the presence of substrate within the earthworm gut.

| Plot | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| A1 | 1089 | 65 | 9.0 | 43 | 27 | 44 |
| A4 | 1139 | 159 | 13 | 91 | 42 | 77 |
| B5 | 530 | 79 | 9.1 | 101 | 18 | 31 |
| C2 | 517 | 78 | 16 | 18 | 70 | 77 |

TABLE 6 NOVEMBER 1986

TABLE 6 Native earthworms.
Species from each plot pooled for analysis and concentrations corrected to eliminate the effect of substrate within the earthworm gut (Stafford & McGrath, 1986). All concentrations expressed as ug/g, dry weight.

**Vegetation type A**

| Species/Plot | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Lumbricus terrestris | | | | | | |
| A1 | 2921 | 23 | 8.8 | 39 | - | - |
| A2 | 2790 | 13 | 0.80 | 60 | - | 2.5 |
| A3 | 3604 | 12 | 1.4 | 45 | 1.6 | 2.7 |
| A4 | 2994 | 12 | 2.5 | 46 | - | - |
| Lumbricus rubellus | | | | | | |
| A3 | 2050 | 15 | 2.5 | 69 | - | 0.34 |
| A4 | 1567 | 17 | 2.3 | 44 | - | - |
| Allolobophora caliginosa | | | | | | |
| A1 | 1115 | 23 | - | 28 | - | - |
| A2 | 1220 | 25 | 1.7 | 24 | 1.0 | - |
| A4 | 1010 | 30 | 4.1 | 30 | 15 | 1.2 |
| Allolobophora chlorotica | | | | | | |
| A1 | 461 | 22 | 0.57 | 35 | - | - |
| A2 | 467 | 21 | 4.6 | 36 | 14 | 6.8 |
| A4 | 309 | 26 | 8.7 | 26 | - | 5.0 |

Means for vegetation type A by earthworm species:

| | | | | | | |
|---|---|---|---|---|---|---|
| L.terrestis | 3077 | 15 | 3.4 | 48 | 1.6 | 18 |
| L.rubellus | 1809 | 16 | 2.4 | 57 | - | 0.34 |
| A.caliginosa | 1115 | 26 | 2.9 | 27 | 7.8 | 1.2 |
| A.chlorotica | 412 | 23 | 4.6 | 35 | 14 | 27 |

TABLE 6 contd...

**Vegetation type B**

| Species/Plot | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Lumbricus rubellus | | | | | | |
| B1 | 945 | 15 | 2.5 | 69 | - | 0.36 |
| B2 | 1149 | 22 | 3.1 | 64 | 3.6 | 0.25 |
| B3 | 1490 | 16 | 0.05 | 67 | - | - |
| B4 | 1625 | 20 | - | 68 | - | - |
| Allolobophora caliginosa | | | | | | |
| B1 | 789 | 19 | 2.85 | 34 | - | 4.3 |
| B3 | 1328 | 22 | - | 26 | - | - |
| Allolobophora chlorotica | | | | | | |
| B1 | 477 | 23 | 11 | 53 | 1.1 | 8.7 |
| B2 | 544 | 32 | 13 | 58 | 30 | 6.0 |
| B3 | 381 | 20 | 3.0 | 43 | 6.5 | 12 |
| Means for vegetation type B by earthworm species: | | | | | | |
| L.rubellus | 1302 | 19 | 1.9 | 67 | 3.6 | 0.31 |
| A.caliginosa | 1059 | 21 | 2.9 | 30 | - | 4.3 |
| A.chlorotica | 467 | 25 | 9.1 | 51 | 13 | 8.9 |

TABLE 6 contd...

**Vegetation type C**

| Species/Plot | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Lumbricus rubellus | | | | | | |
| C2 | 1580 | 13 | 2.9 | 73 | - | - |
| C3 | 1084 | 9 | - | 42 | - | - |
| Allolobophora caliginosa | | | | | | |
| C1 | 975 | 19 | 0.10 | 39 | - | - |
| C3 | 1014 | 13 | 3.2 | 35 | - | - |
| Allolobophora chlorotica | | | | | | |
| C2 | 678 | 30 | 6.3 | 67 | 5.8 | 3.6 |
| C3 | 155 | 12 | 2.4 | 22 | - | - |

**Means for vegetation type C by earthworm species:**

| | | | | | | |
|---|---|---|---|---|---|---|
| L.terrestris | 1565 | 18 | - | 48 | - | - |
| L.rubellus | 1332 | 11 | 2.9 | 57 | - | - |
| A.caliginosa | 995 | 16 | 1.6 | 37 | - | - |
| A.chlorotica | 417 | 28 | 4.3 | 44 | 5.8 | 3.6 |

Appendix B **GRAND ISLAND REFERENCE SITE.**

TABLE 1 MAY 1986

TABLE 1(a) Record of numbers of soil dwelling fauna sampled in pitfall traps, four pooled samples per plot.

| PLOT | COL. | ARAN. | CHIL. | DIPL. | ISOP. | OTHERS |
|---|---|---|---|---|---|---|
| Ref 1 | 61 | 6 | - | 1 | 21 | 1 Acarina |
| Ref 2 | 26 | 1 | - | 6 | 27 | 1 Acarina/1 Diptera<br>1 Opiolones/1 Hymenoptera<br>1 Homoptera/1 Homoptera |
| Ref 3 | 14 | - | - | 5 | 37 | 1 Acarina/1 Diptera |
| Ref 4 | 11 | - | - | 4 | 58 | 2 Acarina/2 Opiolones<br>2 Hemiptera/1 Homoptera |
| Ref 5 | 12 | 1 | - | 4 | 37 | 1 Acarina/1 Diptera<br>2 Hemiptera |

TABLE 1(b) Composition of soil dwelling invertebrate fauna sampled by pitfall traps over a ten day period at Grand Island. Total dry matter (g) and percentage dry matter contribution (%), four pooled samples per plot.
MAY 1986.

| PLOT | | PRED. COL. | ARAN. | CHIL. | HERB. COL. | DIPL. | ISOP. | OTHERS |
|---|---|---|---|---|---|---|---|---|
| Ref 1 | (g) | 0.853 | 0.051 | - | 0.011 | 0.024 | 0.084 | 0.001 |
| | (%) | 83.3 | 5.0 | - | 1.1 | 2.3 | 8.2 | 0.1 |
| Ref 2 | (g) | 1.370 | 0.016 | - | 0.027 | 0.031 | 0.212 | 0.019 |
| | (%) | 81.8 | 1.0 | - | 1.6 | 1.9 | 12.7 | 1.1 |
| Ref 3 | (g) | 0.655 | - | - | 0.013 | 0.011 | 0.247 | 0.001 |
| | (%) | 70.7 | - | - | 1.4 | 1.2 | 26.6 | 0.1 |
| Ref 4 | (g) | 0.871 | - | - | 0.011 | 0.040 | 0.291 | 0.019 |
| | (%) | 70.7 | - | - | 1.0 | 3.2 | 23.6 | 1.5 |
| Ref 5 | (g) | 0.293 | 0.003 | - | 0.005 | 0.011 | 0.208 | 0.013 |
| | (%) | 55.0 | 0.6 | - | 0.9 | 2.1 | 39.0 | 2.4 |

TABLE 1 contd...

TABLE 1(c) Metal concentrations in major groups of invertebrate fauna collected in pitfall traps at Grand Island. Four pooled samples from each plot. MAY 1986.

| Species/Plot | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| CARNIVOROUS SPECIES | | | | | | |
| Predatory COLEOPTERA | | | | | | |
| Ref 1 | 109 | 17 | - | - | - | - |
| Ref 2 | 107 | 17 | - | 2.2 | - | - |
| Ref 3 | 109 | 15 | - | 1.7 | - | - |
| Ref 4 | 108 | 16 | - | - | - | - |
| Ref 5 | 77 | 11 | - | - | - | - |
| ARANEIDA | | | | | | |
| Ref 1 - 5 | 238 | 202 | - | 13 | 3.5 | - |
| OPIOLONES | | | | | | |
| Ref 1 - 5 | 311 | 58 | - | 7.1 | - | - |
| HERBIVOROUS SPECIES | | | | | | |
| Herbivorous COLEOPTERA | | | | | | |
| Ref 1 | 113 | 38 | - | - | 9.3 | - |
| Ref 2 | 96 | 31 | - | - | 7.1 | - |
| Ref 3 | 246 | 60 | - | - | - | - |
| DETRITIVOROUS SPECIES | | | | | | |
| DIPLOPODA | | | | | | |
| Ref 1 | 189 | 231 | - | - | 5.3 | - |
| Ref 2 - 5 | 206 | 205 | 17 | 2.7 | 12 | - |
| ISOPODA | | | | | | |
| Ref 1 | 240 | 175 | - | 4.3 | 4.5 | - |
| Ref 2 | 144 | 123 | 6.3 | 3.0 | 3.7 | - |
| Ref 3 | 512 | 179 | 4.7 | 3.3 | 3.5 | - |
| Ref 4 | 281 | 152 | 4.9 | 3.5 | 3.1 | - |
| Ref 5 | 123 | 138 | 6.8 | 2.4 | 3.5 | 6.5 |

TABLE 2 NOVEMBER 1986

TABLE 2(a) Record of numbers of soil dwelling invertebrates sampled in pitfall traps, Grand Island.

| PLOT | COL. | ARAN. | OPIO. | CHIL. | DIPL. | ISOP. | ORTH. | Others |
|---|---|---|---|---|---|---|---|---|
| Ref 1 | 5 | 3 | 21 | - | 1 | 7 | 1 | 1 Diptera |
| Ref 2 | 11 | 2 | 15 | - | 4 | 15 | - | 1 Diptera/1Hymenoptera<br>1 Lepidoptera L. |
| Ref 3 | 8 | 2 | 19 | 1 | 5 | 13 | - | 1 Acarina/2 Mollusca<br>2 Hymenoptera |
| Ref 4 | 10 | 2 | 24 | - | 1 | 58 | - | 1 Acarina/1 Mollusca<br>6 Hymenoptera |
| Ref 5 | 2 | 2 | 5 | - | - | 26 | 1 | 4 Diptera/2Hymenoptera<br>7 Mollusca/2 Lumb. |

TABLE 2(b) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a seven day period at Grand Island. Total dry matter (g) and percentage dry matter contribution (%), four pooled samples per plot. NOVEMBER 1986

| PLOT | PRED. COL. | ARAN. | OPIO. | HERB. COL. | CHIL. | DIPL. | ISOP. | OTHERS |
|---|---|---|---|---|---|---|---|---|
| Ref 1(g) | 0.0926 | 0.0143 | 0.1148 | - | - | 0.0494 | 0.0242 | 0.0161 |
| (%) | 29.74 | 4.59 | 36.87 | - | - | 15.86 | 7.77 | 5.17 |
| Ref 2(g) | 0.1402 | 0.0082 | 0.0713 | - | - | 0.0991 | 0.0872 | 0.0510 |
| (%) | 30.68 | 1.79 | 15.60 | - | - | 21.68 | 19.08 | 11.16 |
| Ref 3(g) | 0.0686 | 0.0191 | 0.1018 | 0.0356 | 0.0298 | 0.0887 | 0.0265 | 0.0848 |
| (%) | 15.08 | 4.20 | 22.38 | 7.82 | 6.51 | 19.50 | 5.83 | 18.52 |
| Ref 4(g) | 0.1120 | 0.0053 | 0.0846 | 0.0022 | - | 0.0666 | 0.2372 | 0.0423 |
| (%) | 20.36 | 0.96 | 15.38 | 0.40 | - | 12.10 | 43.11 | 7.69 |
| Ref 5(g) | 0.0312 | 0.0027 | 0.0300 | - | - | - | 0.0883 | 0.2092 |
| (%) | 8.63 | 0.75 | 8.30 | - | - | - | 24.43 | 57.89 |

TABLE 2 contd...

TABLE 2(c) Metal concentrations in major groups of invertebrate fauna collected in pitfall traps at Grand Island. Four pooled samples per plot (ug/g, dry weight). NOVEMBER 1986

| Species/Plot | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| CARNIVOROUS SPECIES | | | | | | |
| Predatory COLEOPTERA | | | | | | |
| Ref 1 | 59 | 18 | 1.4 | 1.2 | 29 | 3.1 |
| Ref 2 | 52 | 13 | 0.84 | 0.46 | 6.2 | <1.9 |
| Ref 3 | 71 | 13 | 1.9 | 0.66 | 5.9 | <3.8 |
| Ref 4 | 69 | 19 | 4.1 | 2.2 | 1.0 | 9.0 |
| ARANEIDA | | | | | | |
| Ref 1 | 196 | 68 | <5.3 | 2.7 | 10 | <18 |
| Ref 2 | 206 | 58 | 18 | 7.7 | 18 | 37 |
| Ref 3 | 173 | 57 | 5.1 | 2.9 | 9.8 | <14 |
| Ref 4 & 5 | 199 | 74 | 9.2 | 2.1 | 31 | <32 |
| OPIOLONES | | | | | | |
| Ref 1 | 194 | 34 | 4.9 | 6.9 | 6.1 | 5.7 |
| Ref 2 | 197 | 30 | 3.9 | 5.4 | 4.2 | 5.3 |
| Ref 3 | 170 | 36 | 4.0 | 6.3 | 2.9 | <2.6 |
| Ref 4 | 246 | 38 | 4.4 | 7.1 | 4.9 | 5.7 |
| Ref 5 | 315 | 58 | 4.9 | 9.4 | 2.5 | 14 |
| CHILOPODA | | | | | | |
| Ref 3 | 148 | 41 | 3.2 | 1.5 | <0.65 | <8.9 |
| HERBIVOROUS SPECIES | | | | | | |
| Herbivorous COLEOPTERA | | | | | | |
| Ref 1 - 5 | 86 | 34 | 2.6 | 0.65 | 2.3 | <7.4 |
| DETRITIVOROUS SPECIES | | | | | | |
| DIPLOPODA | | | | | | |
| Ref 1 | 142 | 288 | 6.7 | 4.2 | 8.1 | 8.5 |
| Ref 2 | 225 | 112 | 4.7 | 1.9 | 4.8 | 7.8 |
| Ref 3 | 167 | 75 | 5.2 | 2.3 | 2.6 | 6.8 |
| Ref 4 | 106 | 56 | 1.8 | 1.1 | 0.59 | <4.0 |
| ISOPODA | | | | | | |
| Ref 1 | 303 | 85 | 17 | 13 | 21 | 27 |
| Ref 2 | 214 | 57 | 6.4 | 7.8 | 3.8 | 7.8 |
| Ref 3 | 229 | 41 | 12 | 7.0 | 4.2 | 16 |
| Ref 4 | 242 | 136 | 11 | 7.5 | 5.9 | 13 |
| Ref 5 | 107 | 74 | 5.5 | 5.7 | 2.6 | 6.6 |

TABLE 3 NOVEMBER 1986

TABLE 3 Native earthworms.
Composite samples of each species per plot expresses as ug/g. dry weight. All results corrected to eliminate the effect of soil within the earthworm gut.

| Species/Plot | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Lumbricus terrestris | | | | | | |
| Ref 1 & 2 | 392 | 2.1 | - | 5.4 | 2.2 | - |
| Ref 3 | 371 | 2.3 | 3.7 | 13 | 0.29 | 4.0 |
| Ref 4 & 5 | 287 | 2.0 | 0.15 | 8.4 | 0.45 | - |
| Lumbricus rubellus | | | | | | |
| Ref 1 & 2 | 384 | 6.6 | 5.0 | 10 | 1.5 | 1.2 |
| Ref 3 | 467 | 4.9 | 2.3 | 14 | 4.0 | 1.7 |
| Ref 4 & 5 | 438 | 2.4 | 0.35 | 15 | 2.1 | - |
| Allolobophora caliginosa | | | | | | |
| Ref 1 & 2 | 514 | 7.5 | 2.5 | 33 | 2.1 | 2.1 |
| Ref 3 | 509 | 4.3 | 1.1 | 37 | 4.2 | 0.29 |
| Ref 4 & 5 | 415 | 4.6 | 3.4 | 33 | 1.3 | 5.2 |
| Allolobophora chlorotica | | | | | | |
| Ref 1 & 2 | 304 | 10 | 5.6 | 22 | 2.4 | - |
| Ref 4 & 5 | 303 | 5.3 | 2.1 | 14 | 2.6 | 2.3 |
| Mean metal concentrations for reference site by earthworm species: | | | | | | |
| L.terrestris | 350 | 2.1 | 1.3 | 8.8 | 0.99 | 4.0 |
| L.rubellus | 430 | 4.6 | 2.5 | 13 | 2.5 | 1.5 |
| A.caliginosa | 479 | 5.5 | 2.3 | 34 | 2.5 | 2.5 |
| A.chlorotica | 304 | 7.8 | 3.9 | 18 | 2.5 | 2.3 |

Appendix C **BLACK ROCK HARBOUR CDF.**

TABLE 1 MAY 1986

TABLE 1(a) Record of numbers of soil dwelling fauna sampled in pitfall traps.

| PLOT | COL. | ARAN. | OTHERS |
|---|---|---|---|
| 1 | 3 | 6 | 3 Hymenoptera/3 Diptera |
| 2 | 3 | 4 | 4 Hymenoptera/3 Diptera/1 Hemiptera |
| 3 | - | 6 | 2 Hymenoptera/2 Diptera/1 Hemiptera |
| 4 | 1 | 3 | 1 Diptera |
| 5 | 2 | - | 1 Hemiptera |
| 6 | - | 2 | 1 Hymenoptera/1 Diptera |
| 7 | 4 | 1 | 1 Diptera |
| 8 | 1 | 4 | 2 Hymenoptera/3 Diptera |
| 9 | 3 | 2 | 1 Hymenoptera/2 Diptera |
| 10 | 3 | - | 3 Hymenoptera/1 Diptera |
| 11 | 2 | 4 | 1 Hymenoptera/2 Diptera |
| 12 | 1 | 1 | 2 Diptera/1 Hemiptera |
| 13 | 3 | - | 1 Hymenoptera/1 Diptera/1 Hemiptera |
| 14 | 4 | - | 2 Diptera |
| 15 | 2 | 4 | 3 Diptera |
| 16 | 2 | 3 | 1 Hymenoptera |
| 17 | 3 | 2 | 3 Hymenoptera/1 Diptera |
| 18 | 1 | 1 | |
| 19 | 1 | 4 | 1 Hymenoptera/2 Diptera/1 Lepidoptera L. |
| 20 | 3 | 3 | 4 Hymenoptera/1 Diptera |
| 21/22 | 4 | 9 | 3 Hymenoptera/3 Diptera/1 Opiolones |
| 31/32 | 8 | 2 | 4 Hymenoptera |

TABLE 1(a) contd...

TRANSECT PLOTS:

| PLOT | COL. | ARAN. | OTHERS |
|---|---|---|---|
| 23 | 5 | 4 | 4 Hymenoptera/4 Diptera/1 Chilopoda/ 1 Jassidae |
| 24 | 11 | 1 | 5 Hymenoptera/8 Diptera/1 Hemiptera/ 2 Coleoptera L./8 Opiolones/1 Acarina |
| 25 | 4 | 3 | 4 Hymenoptera/2 Jassidae/7 Opiolones |
| 26 | 9 | 3 | 22 Hymenoptera/3 Diptera/1 Hemiptera/1 Isopoda 12 Opiolones/2 Chilopoda/1 Acarina |
| 27 | 1 | 2 | 2 Isopoda |

TABLE 1(b) Identification of Coleoptera. MAY 1986

| PLOT | SUB-ORDER | FAMILY | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|
| 1 | Geodephaga | Carabidae | 2 |
| | Rhynchophora | Curculionidae | 1 |
| 2 | Geodephaga | Carabidae | 2 |
| | Heteromera | Anthicidae | 1 |
| 4 | Geodephaga | Carabidae | 1 |
| 5 | Rynchophora | Curculionidae | 2 |
| 7 | Geodephaga | Carabidae | 3 |
| | Rhyncophora | Curculionidae | 1 |
| 8 | Geodephaga | Carabidae | 1 |
| 9 | Geodephaga | Carabidae | 2 |
| | Heteromera | Anthicidae | 1 |
| 10 | Geodephaga | Carabidae | 3 |
| 11 | Geodephaga | Carabidae | 2 |
| 12 | Rhynchophora | Curculionidae | 1 |
| 13 | Geodephaga | Carabidae | 1 |
| | Heteromera | Anthicidae | 1 |
| | Rhynchophora | Curculionidae | 1 |
| 14 | Geodephaga | Cicindelidae | 1 |
| | Geodephaga | Carabidae | 1 |
| | Rhyncophora | Curculionidae | 1 |
| | Clavicornia | Atomaria | 1 |
| 15 | Brachelytra | Staphylinidae | 1 |
| | Rhyncophora | Curculionidae | 1 |
| 16 | Rhyncophora | Curculionidae | 2 |
| 17 | Geodephaga | Cicindelidae | 1 |
| | Geodephaga | Carabidae | 1 |
| | Rhyncophora | Curculionidae | 1 |
| 18 | Geodephaga | Carabidae | 1 |
| 19 | Heteromera | Anthicidae | 1 |

Table 1(b) contd...

| PLOT | SUB-ORDER | FAMILY | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|
| 20 | Brachelytra | Staphylinidae | 2 |
| | Heteromera | Anthicidae | 1 |
| 21 | Geodephaga | Carabidae | 1 |
| | Heteromera | Anthicidae | 1 |
| 22 | Rhyncophora | Curculionidae | 2 |
| 31 | Geodephaga | Carabidae | 1 |
| | Rhyncophora | Curculionidae | 2 |
| | Heteromera | Anthicidae | 3 |
| 32 | Geodephaga | Carabidae | 1 |
| | Heteromera | Anthicidae | 1 |
| TRANSECT PLOTS: | | | |
| 23 | Geodephaga | Carabidae | 3 |
| | Rhyncophora | Curculionidae | 1 |
| | Phytophaga | Chrysomelidae | 1 |
| 24 | Geodephaga | Carabidae | 6 |
| | Rhyncophora | Curculionidae | 2 |
| | Brachelytra | Staphylinidae | 1 |
| | Clavicornia | Atomaria | 1 |
| 25 | Rhyncophora | Curculionidae | 1 |
| | Brachelytra | Staphylinidae | 2 |
| | Clavicornia | Atomaria | 1 |
| 26 | Geodephaga | Carabidae | 3 |
| | Brachelytra | Staphylinidae | 1 |
| | Clavicornia | Nitidulidae | 1 |
| | Phytophaga | Chrysomelidae | 2 |
| 27 | Clavicornia | Nitidulidae | 1 |

TABLE 1(c) Composition of soil dwelling invertebrate fauna sampled by pitfall trapping over a ten day period at Black Rock. Total dry matter (g) and percentage dry matter contribution (%), three samples per plot. MAY 1986.

| PLOT | PRED. COL. | ARAN. | HERB. COL. | OTHERS | TOTAL |
|---|---|---|---|---|---|
| 1 (g) | 0.0135 | 0.0184 | 0.004 | 0.0170 | 0.0529 |
| (%) | 25.5 | 34.8 | 7.6 | 32.1 | |
| 2 (g) | 0.026 | 0.0153 | 0.0018 | 0.0165 | 0.0596 |
| (%) | 43.6 | 25.7 | 3.0 | 27.7 | |
| 3 (g) | - | 0.0223 | - | 0.0085 | 0.0308 |
| (%) | | 72.4 | | 27.6 | |
| 4 (g) | 0.0166 | 0.0091 | - | 0.0075 | 0.0332 |
| (%) | 50.0 | 27.4 | | 22.6 | |
| 5 (g) | - | - | 0.0076 | 0.0018 | 0.0094 |
| (%) | | | 80.9 | 19.1 | |
| 6 (g) | - | 0.003 | - | 0.0037 | 0.0067 |
| (%) | | 44.8 | | 55.2 | |
| 7 (g) | 0.0472 | 0.0045 | 0.0163 | 0.0016 | 0.0696 |
| (%) | 67.8 | 6.5 | 23.4 | 2.3 | |
| 8 (g) | 0.0148 | 0.0149 | - | 0.0072 | 0.0369 |
| (%) | 40.1 | 40.4 | | 19.5 | |
| 9 (g) | 0.0283 | 0.0076 | 0.0006 | 0.0053 | 0.0418 |
| (%) | 67.7 | 18.2 | 1.4 | 12.7 | |
| 10(g) | 0.0289 | - | - | 0.0152 | 0.0531 |
| (%) | 54.4 | | | 28.6 | |
| 11(g) | 0.0308 | 0.0077 | - | 0.0045 | 0.0430 |
| (%) | 71.6 | 17.9 | | 10.5 | |
| 12(g) | - | 0.0012 | 0.0039 | 0.0035 | 0.0086 |
| (%) | | 14.0 | 45.3 | 40.7 | |
| 13(g) | 0.0073 | - | 0.0069 | 0.0088 | 0.0230 |
| (%) | 31.7 | | 30.0 | 38.3 | |
| 14(g) | 0.0248 | - | 0.0049 | 0.0014 | 0.0311 |
| (%) | 79.7 | | 15.8 | 4.5 | |
| 15(g) | 0.0010 | 0.0118 | 0.0027 | 0.0034 | 0.0189 |
| (%) | 5.3 | 62.4 | 14.3 | 18.0 | |

TABLE 1(c) Contd...

| PLOT | PRED. COL. | ARAN. | HERB. COL. | OTHERS | TOTAL |
|---|---|---|---|---|---|
| 16(g) | - | 0.0047 | 0.0064 | 0.0034 | 0.0145 |
| (%) | | 32.4 | 44.1 | 23.4 | |
| 17(g) | 0.0371 | 0.0043 | 0.0031 | 0.0075 | 0.052 |
| (%) | 71.3 | 8.3 | 6.0 | 14.4 | |
| 18(g) | 0.0167 | 0.0047 | - | - | 0.0214 |
| (%) | 78.0 | 22.0 | | | |
| 19(g) | - | 0.0108 | 0.0018 | 0.0031 | 0.0157 |
| (%) | | 68.8 | 11.5 | 19.7 | |
| 20(g) | 0.0019 | 0.0096 | 0.0010 | 0.0316 | 0.0451 |
| (%) | 4.3 | 21.8 | 2.3 | 71.7 | |
| 21(g) | 0.0217 | 0.0101 | 0.0004 | 0.0067 | 0.0389 |
| (%) | 55.8 | 26.0 | 1.0 | 17.2 | |
| 22(g) | - | 0.0140 | 0.0070 | 0.0021 | 0.0231 |
| (%) | - | 60.6 | 30.3 | 9.1 | |
| 31(g) | 0.0197 | 0.0042 | 0.0074 | 0.0051 | 0.0364 |
| (%) | 54.1 | 11.5 | 20.3 | 14.0 | |
| 32(g) | 0.0069 | 0.0025 | 0.0007 | 0.0084 | 0.0185 |
| (%) | 37.3 | 13.5 | 3.8 | 45.4 | |
| TRANSECT PLOTS: | | | | | |
| 23(g) | 0.0179 | 0.0070 | 0.0039 | 0.0228 | 0.0516 |
| (%) | 34.7 | 13.6 | 7.6 | 44.2 | |
| 24(g) | 0.0425 | 0.0049 | 0.0424 | 0.0339 | 0.1233 |
| (%) | 34.5 | 4.0 | 34.4 | 27.5 | |
| 25(g) | 0.0020 | 0.0035 | 0.0040 | 0.0167 | 0.0262 |
| (%) | 7.6 | 13.4 | 15.3 | 63.7 | |
| 26(g) | 0.0536 | 0.0105 | 0.0039 | 0.0594 | 0.1274 |
| (%) | 42.1 | 8.2 | 3.1 | 46.6 | |
| 27(g) | - | 0.0372 | 0.0021 | 0.0214 | 0.0607 |
| (%) | | 61.3 | 3.5 | 35.3 | |

TABLE 1(d) Metal concentrations in major groups of invertebrate fauna, three pooled samples per treatment (ug/g, dry weight). MAY 1986

| PLOTS | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| **(1) Predatory COLEOPTERA** | | | | | | |
| 2,10,14,16 | 67 | 65 | (3.3) | 1.5 | 42 | (8.2) |
| 1,9,13,17 | 72 | 49 | (3.9) | (0.72) | 30 | (9.0) |
| 5,8,11,19 | 87 | 52 | (2.4) | (0.80) | 19 | <6.0 |
| 4,7,15,18 | 73 | 63 | (7.5) | (0.78) | 21 | (8.1) |
| 21,22,31,32 | 99 | 91 | (4.7) | (1.7) | 52 | (15) |
| Transect | 94 | 31 | 4.9 | (0.38) | 8.2 | (8.2) |
| **(2) ARANEIDA** | | | | | | |
| 2,10,14,16 | 271 | 438 | (13) | 11 | 29 | (<18) |
| 1,9,13,17 | 186 | 344 | (8.1) | 9.2 | 21 | (11) |
| 5,8,11,19 | 407 | 435 | (13) | 16 | 18 | (<9.3) |
| 4,7,15,18 | 318 | 356 | (11) | 12 | 20 | (<10.6) |
| 3,6,12,20 | 470 | 427 | (92) | 17 | 256 | (10.5) |
| 21,22,31,32 | 328 | 500 | (13) | 15 | 29 | (10.8) |
| Transect | 314 | 297 | 13 | 12 | 13 | (12) |
| **(3) Herbivorous COLEOPTERA** | | | | | | |
| 2,10,14,16 | 256 | 70 | (10) | (1.5) | 39 | <29 |
| 1,9,13,17 | 168 | 98 | (14) | (1.4) | 55 | (26) |
| 5,8,11,19 | 353 | 117 | (15) | (3.0) | 52 | <43 |
| 4,7,15,18 | 79 | 52 | <1.6 | (0.45) | 15 | <5.5 |
| 21,22,31,32 | 200 | 85 | <5.9 | (1.5) | 25 | <21 |
| Transect | 229 | 117 | (17) | (1.9) | 18 | <19 |

TABLE 2 NOVEMBER 1986

Table 2(a) Record of numbers of soil dwelling fauna sampled in pitfall traps, three pooled samples per plot.

| PLOT | COL.*[1] | ARAN. | OTHERS |
|---|---|---|---|
| 1 | 9 | 3 | 3 Hymenoptera/3 Diptera<br>1 Acarina/1 Neuroptera/1 Homoptera/1 Chilopoda |
| 2 | 10 | 2 | 1 Hymenoptera/1 Acarina/4 Homoptera<br>2 Orthoptera/2 Coleoptera(adults) |
| 3 | 2 | - | 1 Diptera/3 Homoptera/3 Orthoptera<br>1 Dermaptera/1 Neuroptera/1 Odonata |
| 4 | 1 | 1 | 2 Diptera/1 Isopoda |
| 5 | 1 | - | 2 Diptera |
| 6 | 3 | 2 | 1 Hymenoptera/1 Acarina<br>2 Coleoptera(adult)/1 Homoptera/6 Neuroptera |
| 7 | 1 | 4 | 2 Hymenoptera/1 Hemiptera<br>1 Acarina/1 Coleoptera(adult) |
| 8 | 1 | 2 | 1 Diptera/1 Hemiptera/1 Orthoptera |
| 9 | 6 | 5 | 5 Hymenoptera/3 Diptera/1 Dermaptera<br>1 Coleoptera L. |
| 10 | 18 | 3 | 1 Diptera/3 Coleoptera L. |
| 11 | 47 | 3 | 1 Hymenoptera/1 Diptera/1 Hemiptera<br>1 Odonata/1 Orthoptera/2 Coleoptera(adults) |
| 12 | 5 | 5 | 1 Hymenoptera/3 Diptera/1 Hemiptera |
| 13 | 20 | 3 | 2 Hymenoptera/1 Diptera/2 Hemiptera<br>1 Coleoptera L./1 Lepidoptera L. |
| 14 | 10 | 2 | 1 Hymenoptera/2 Diptera/3 Hemiptera<br>1 Orthoptera/1 Coleoptera(adult) |
| 15 | 10 | - | 1 Hymenoptera/3 Hemiptera/1 Opiolones |
| 16 | - | 2 | 1 Diptera |
| 17 | 18 | 3 | 1 Hymenoptera |
| 18 | 21 | - | 1 Hymenoptera/1 Diptera/1 Hemiptera<br>1 Lepidoptera/1 Coccinellidae L./2 Coleoptera |
| 19 | 28 | 6 | 4 Diptera/1 Isopoda/1 Opiolones<br>1 Coleoptera(adult) |
| 20 | 9 | 2 | 1 Hymenoptera/3 Diptera/1 Hemiptera |
| 21/22 | 18 | 3 | 3 Hymenoptera/2 Diptera/1 Opiolones<br>8 Hemiptera/1 Coleoptera(adult) |
| 31/32 | 7 | 6 | 2 Diptera/2 Lepidoptera L. |

[1] Coleoptera sampled were all carabid larvae.

TABLE 2(a) contd...

| PLOT | COL.*[a] | ARAN. | OTHERS |
|---|---|---|---|
| 23 | 76 | 2 | 1 Hymenoptera/6 Diptera/1 Chilopoda/2Hemiptera 1 Isopoda/4 Coleoptera(adults) |
| 24 | 10 | 1 | 4 Hymenoptera/4 Hemiptera/3 Opiolones 3 Coleoptera(adult)/5 Diptera |
| 25 | 6 | 3 | 8 Hymenoptera/18 Diptera/8 Hemiptera 1 Orthoptera/2 Isopoda/6 Coleoptera |
| 26 | 4 | 4 | 23 Diptera/1 Isopoda 7 Coleoptera(adults) |
| 27 | - | - | 9 Diptera/2 Hemiptera/2 Isopoda |

[a]All Carabid larvae.

TABLE 2(b) Metal concentrations in major groups of invertebrate fauna, three pooled samples per treatment (ug/g, dry weight). NOVEMBER 1986

| PLOTS | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| (1) Carabid larvae | | | | | | |
| 2,10,14,16 | 103 | 159 | 16 | 2.6 | 54 | 21 |
| 1,9,13,17 | 131 | 310 | 19 | 2.2 | 34 | 13 |
| 5,8,11,19 | 86 | 187 | 7.8 | 1.3 | 24 | 9.1 |
| 4,7,15,18 | 156 | 208 | 12 | 3.7 | 26 | 16 |
| 3,12,20,6 | 154 | 196 | 19 | 4.2 | 15 | 29 |
| 21,22,31,32 | 97 | 187 | 6.0 | 2.3 | 37 | 15 |
| Transect | 75 | 134 | 9.7 | 1.4 | 39 | 18 |
| (2) ARANEIDA | | | | | | |
| 2,10,14,16 | 225 | 556 | 11 | 5.7 | 55 | 19 |
| 1,9,13,17 | 265 | 388 | 11 | 8.6 | 29 | 5.1 |
| 5,8,11,19 | 337 | 521 | 6.1 | 7.9 | 35 | 7.1 |
| 4,7,15,18 | 472 | 425 | 11 | 13 | 36 | 20 |
| 3,6,12,20 | 361 | 507 | 8.6 | 9.8 | 35 | 10 |
| 21,22,31,32 | 295 | 259 | 7.7 | 7.0 | 31 | 11 |
| Transect | 352 | 128 | 12 | 4.4 | 7.7 | 8.1 |
| (3) Predatory COLEOPTERA(adult) | | | | | | |
| whole site | 131 | 80 | 4.3 | 1.3 | 34 | 6.4 |
| Transect | 100 | 32 | 7.4 | 1.3 | 9.7 | 11 |

APPENDIX D <u>OTTAWA MINE SPOIL RECLAMATION SITE</u>

TABLE 1 MAY 1986

TABLE 1(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

| PLOT | COL. | ARAN. | CHIL. | DIPL. | ISOP. | ORTH. | OTHERS |
|---|---|---|---|---|---|---|---|
| 1 | 19 | 23 | - | 11 | - | 7 | 7 Diptera/81 Hymenoptera/ 1 Lepidoptera L. |
| 2a | 15 | 11 | 3 | 2 | 3 | 7 | 13 Diptera/1 Hemiptera/ 38 Hymenoptera/8 Lepidoptera L. 1 Coleoptera L. |
| 2cd | 23 | 44 | - | 2 | 1 | 1 | 7 Diptera/11 Hymenoptera 6 Hemiptera/2 Lepidoptera L. |
| 2e | 16 | 17 | - | 3 | - | 2 | 1 Diptera/1 Hemiptera 26 Hymenoptera/1 Neuroptera |
| 3a | 19 | 5 | - | 2 | 6 | 1 | 11 Diptera/4 Hemiptera 20 Hymenoptera/1 Acarina 10 Lepidoptera L. |
| 3cd | 22 | 48 | - | - | 13 | 5 | 7 Diptera/9 Hemiptera 11 Hymenoptera/6 Lepidoptera L. 11 Oligochaeta |
| 3e | 17 | 20 | - | 1 | 3 | 5 | 9 Diptera/12 Hymenoptera 3 Lepidoptera L./3 Oligochaeta |
| 4a | 20 | 15 | - | 4 | 3 | 5 | 8 Diptera/7 Lepidoptera L. 7 Hymenoptera |
| 4cd | 30 | 26 | - | 2 | 15 | 4 | 7 Diptera/20 Hymenoptera 1 Hemiptera/3 Lepidoptera L. |
| 4e | 24 | 28 | 1 | - | 30 | 4 | 2 Diptera/2 Hemiptera 9 Hymenoptera/3 Lepidoptera L. 3 Oligochaeta |

TABLE 1(b) Identification of Coleoptera. May 1986

| PLOT | SUB-ORDER | FAMILY | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|
| 1 | Geodephaga | Carabidae | 2 |
| | Rhynchophora | Curculionidae | 1 |
| | Brachelytra | Staphylinidae | 1 |
| | Sternoxia | Elateridae | 4 |
| | Phytophaga | Chrysomelidae | 1 |
| 2a | Geodephaga | Carabidae | 1 |
| | Rhynchophora | Curculionidae | 1 |
| | Brachelytra | Staphylinidae | 2 |
| | Sternoxia | Elateridae | 3 |
| | Clavicornia | Atomaria | 5 |
| | Lamellicornia | Scarabaeidae | 1 |
| 2cd | Geodephaga | Carabidae | 5 |
| | Brachelytra | Staphylinidae | 5 |
| | Sternoxia | Elateridae | 4 |
| | Clavicornia | Atomaria | 8 |
| | Clavicornia | Nitidulidae | 1 |
| 2e | Geodephaga | Carabidae | 3 |
| | Rhynchophora | Curculionidae | 1 |
| | Brachelytra | Staphylinidae | 1 |
| | Phytophaga | Chrysomelidae | 1 |
| | Clavicornia | Atomaria | 10 |
| | Clavicornia | Nitidulidae | 1 |
| 3a | Geodephaga | Carabidae | 1 |
| | Rhynchophora | Curculionidae | 1 |
| | Brachelytra | Staphylinidae | 2 |
| | Clavicornia | Atomaria | 10 |
| | Clavicornia | Nitidulidae | 1 |
| | Heteromera | Anthicidae | 1 |
| | Sternoxia | Elateridae | 1 |
| | Lamellicornia | Scarabaeidae | 1 |
| 3cd | Geodephaga | Carabidae | 3 |
| | Brachelytra | Staphylinidae | 4 |
| | Phytophaga | Chrysomelidae | 1 |
| | Clavicornia | Atomaria | 10 |
| | Clavicornia | Nitidulidae | 2 |
| | Sternoxia | Elateridae | 1 |

Table 1(b) contd...

| PLOT | SUB-ORDER | FAMILY | NUMBER IN POOLED SAMPLE AT EACH PLOT |
|---|---|---|---|
| 3e | Brachelytra | Staphylinidae | 1 |
| | Clavicornia | Atomaria | 5 |
| | Clavicornia | Nitidulidae | 2 |
| | Clavicornia | Phalacridae | 2 |
| | Sternoxia | Elateridae | 6 |
| 4a | Brachelytra | Staphylinidae | 4 |
| | Clavicornia | Atomaria | 6 |
| | Clavicornia | Nitidulidae | 4 |
| | Clavicornia | Phalacridae | 4 |
| | Sternoxia | Elateridae | 2 |
| 4cd | Geodephaga | Carabidae | 2 |
| | Clavicornia | Atomaria | 11 |
| | Clavicornia | Nitidulidae | 4 |
| | Sternoxia | Elateridae | 9 |
| | Phytophaga | Chrysomelidae | 2 |
| 4e | Geodephaga | Carabidae | 8 |
| | Rhynchophora | Curculionidae | 4 |
| | Brachelytra | Staphylinidae | 1 |
| | Clavicornia | Nitidulidae | 3 |
| | Heteromera | Anthicidae | 1 |
| | Sternoxia | Elateridae | 3 |
| | Lamellicornia | Scarabaeidae | 1 |
| | Phytophaga | Chrysomelidae | 3 |

TABLE 1 contd...

TABLE 1(c) Composition of soil dwelling invertebrate fauna sampled by pitfall traps over a ten day period at Ottawa. Total dry matter (g) and percentage dry matter contribution (%), four pooled samples per plot.
NOVEMBER 1986.

| PLOT | | PRED. COL. | ARAN. | OPIO. | CHIL. | HERB. COL. | DIPL. | ISOP. | ORTH. | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (g) | 0.1015 | 0.0784 | 0.000 | 0.000 | 0.0319 | 0.1066 | 0.000 | 0.2728 | 0.1608 |
| | (%) | 13.5 | 10.4 | - | - | 4.2 | 14.2 | - | 36.3 | 21.4 |
| 2a | (g) | 0.1350 | 0.0400 | 0.000 | 0.0114 | 0.006 | 0.0162 | 0.0164 | 0.0483 | 0.2913 |
| | (%) | 23.9 | 7.1 | - | 2.0 | 1.1 | 2.9 | 2.9 | 8.6 | 51.6 |
| 2cd | (g) | 0.0847 | 0.2100 | 0.000 | 0.000 | 0.0146 | 0.0232 | 0.0067 | 0.0380 | 0.0466 |
| | (%) | 20.0 | 49.6 | - | - | 3.4 | 5.5 | 1.6 | 9.0 | 11.0 |
| 2e | (g) | 0.0557 | 0.0554 | 0.000 | 0.000 | 0.0056 | 0.0618 | 0.000 | 0.2051 | 0.0283 |
| | (%) | 13.5 | 13.4 | - | - | 1.4 | 15.0 | - | 49.8 | 6.9 |
| 3a | (g) | 0.0380 | 0.017 | 0.000 | 0.000 | 0.0138 | 0.012 | 0.0291 | 0.0746 | 0.3975 |
| | (%) | 6.5 | 2.9 | - | - | 2.4 | 2.1 | 5.0 | 12.8 | 68.3 |
| 3cd | (g) | 0.0768 | 0.3071 | 0.000 | 0.000 | 0.0158 | 0.000 | 0.1000 | 0.1454 | 1.2225 |
| | (%) | 4.1 | 16.4 | - | - | 0.80 | - | 5.4 | 7.8 | 65.5 |
| 3e | (g) | 0.0014 | 0.1141 | 0.000 | 0.000 | 0.0143 | 0.0068 | 0.0094 | 0.2731 | 0.3974 |
| | (%) | 0.20 | 14.0 | - | - | 1.8 | 0.80 | 1.2 | 33.4 | 48.8 |
| 4a | (g) | 0.0016 | 0.0313 | 0.003 | 0.000 | 0.0115 | 0.0513 | 0.0512 | 0.2483 | 0.5083 |
| | (%) | 0.20 | 3.5 | 0.30 | - | 1.3 | 5.7 | 5.6 | 27.4 | 56.13 |
| 4cd | (g) | 0.0528 | 0.1681 | 0.000 | 0.000 | 0.0209 | 0.0267 | 0.0711 | 0.2864 | 0.0861 |
| | (%) | 7.4 | 23.6 | - | - | 2.9 | 3.7 | 10.0 | 40.2 | 12.1 |
| 4e | (g) | 0.0958 | 0.1069 | 0.000 | 0.0073 | 0.0450 | 0.000 | 0.1269 | 0.2074 | 0.0118 |
| | (%) | 15.9 | 17.8 | - | 1.2 | 7.5 | - | 21.1 | 34.5 | 2.0 |

TABLE 1(d) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). MAY 1986

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | 78 | 12 | - | 1.6 | 18 | 3.7 |
| 2a | 111 | 13 | - | 0.85 | 8.6 | 4.5 |
| 2cd | 83 | 16 | - | - | 6.0 | 6.0 |
| 2e | | | Sample lost | | | |
| 3a | 136 | 16 | - | - | 23 | 15 |
| 3cd | 94 | 15 | - | - | 6.9 | 8.9 |
| 3e | | | Insufficient sample size | | | |
| 4a | | | Insufficient sample size | | | |
| 4cd | 72 | 13 | - | - | 4.5 | 6.3 |
| 4e | 110 | 29 | - | - | 5.0 | 11 |

(2) ARANEIDA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | 244 | 164 | 13 | 5.2 | 13 | (9.1) |
| 2a | 305 | 52 | (6.6) | 4.4 | 7.9 | (36) |
| 2cd | 284 | 58 | (2.6) | 5.1 | 3.3 | (10) |
| 2e | 326 | 73 | (4.5) | 7.4 | 3.1 | (18) |
| 3a | 332 | 95 | (5.5) | (5.0) | (5.7) | (41) |
| 3cd | 369 | 106 | (3.8) | 7.9 | 4.7 | (13) |
| 3e | 428 | 121 | (3.2) | 9.0 | 3.7 | (13) |
| 4a | 267 | 59 | (17.9) | 6.3 | 5.6 | (17) |
| 4cd | 299 | 133 | (2.3) | 5.8 | 5.0 | (15) |
| 4e | 327 | 122 | (3.1) | 7.5 | 5.2 | (15) |

(3) CHILOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 2a | 608 | 50 | (7.8) | (3.1) | 11 | (37) |

TABLE 1(d) contd....

HERBIVOROUS SPECIES

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| (1) Herbivorous COLEOPTERA | | | | | | |
| 1 | 97 | 38 | (14) | (1.2) | (2.7) | (15) |
| 2a | | | Insufficient sample size | | | |
| 2cd | 132 | 25 | (7.0) | (1.5) | (4.4) | (27) |
| 2e | | | Insufficient sample size | | | |
| 3a | 117 | 34 | (11) | (<0.97) | (7.0) | (37) |
| 3cd | 133 | 27 | (6.3) | (1.9) | 9.9 | (30) |
| 3e | 211 | 34 | (19) | (1.5) | (9.3) | (28) |
| 4a | 179 | 40 | (19) | (1.3) | (7.7) | (56) |
| 4cd | 111 | 25 | (14) | (1.0) | 9.0 | (20) |
| 4e | 133 | 30 | (3.0) | (0.83) | 4.9 | (10) |
| (2) ORTHOPTERA | | | | | | |
| 1 | 124 | 25 | 9.0 | (0.57) | 4.9 | (4.3) |
| 2a | 188 | 30 | (2.6) | (1.8) | 1.9 | (14) |
| 2cd | 213 | 26 | (<2.0) | (2.5) | <0.51 | (11) |
| 2e | 102 | 32 | (1.0) | 0.71 | 0.61 | (2.9) |
| 3a | 251 | 33 | (5.7) | 1.8 | 20 | 63 |
| 3cd | 146 | 49 | (1.6) | 1.8 | 1.4 | (6.2) |
| 3e | 264 | 84 | (2.1) | 1.8 | 2.1 | (9.2) |
| 4a | 146 | 29 | (0.69) | (0.59) | (0.65) | (3.5) |
| 4cd | 190 | 74 | (1.3) | 0.77 | 2.2 | (7.9) |
| 4e | 151 | 62 | (1.6) | (0.64) | 1.9 | (9.2) |
| (3) LEPIDOPTERA LARVAE | | | | | | |
| 1 | 80 | 24 | 8.3 | (0.85) | 4.6 | (7.2) |
| 2a | 209 | 26 | (3.2) | 2.4 | 8.6 | (12) |
| 2cd | 170 | 37 | (2.9) | (3.3) | 9.0 | (14) |
| 2e | | | Insufficient sample size | | | |
| 3a | 200 | 17 | (1.5) | 1.2 | 3.2 | (11) |
| 3cd | 148 | 30 | (1.4) | 1.7 | 3.0 | (7.0) |
| 3e | 129 | 22 | (<1.3) | 2.2 | 2.0 | <4.6 |
| 4a | 157 | 32 | (2.9) | 1.2 | 3.5 | (12) |
| 4cd | 125 | 20 | (1.6) | 0.28 | 1.8 | 89 |
| 4e | 132 | 14 | (0.79) | (0.66) | 0.83 | 2.2 |

TABLE 1(d) contd....

DETRITIVOROUS SPECIES

(1) DIPLOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | 288 | 90 | 8.4 | 1.0 | 6.1 | (6.5) |
| 2a | 456 | 99 | (12) | (1.9) | 4.5 | (50) |
| 2cd | 453 | 77 | (6.5) | (2.9) | 2.8 | (16) |
| 2e | 323 | 89 | (2.9) | (1.2) | 3.3 | (12) |
| 3a | | | Insufficient sample size | | | |
| 3cd | | | Insufficient sample size | | | |
| 3e | | | Insufficient sample size | | | |
| 4a | 339 | 125 | (3.4) | 2.0 | 5.6 | (21) |
| 4cd | | | Insufficient sample size | | | |
| 4e | | | Insufficient sample size | | | |

(2) ISOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | | | Insufficient sample size | | | |
| 2a | 706 | 306 | (6.6) | 7.3 | 7.4 | (35) |
| 2cd | | | Insufficient sample size | | | |
| 2e | | | Insufficient sample size | | | |
| 3a | 907 | 257 | (5.7) | 7.1 | 9.8 | (35) |
| 3cd | 805 | 241 | 11 | 14 | 10 | 30 |
| 3e | | | Insufficient sample size | | | |
| 4a | 505 | 221 | (8.7) | 5.9 | 11 | (35) |
| 4cd | 311 | 77 | (2.0) | 5.8 | 5.0 | (24) |
| 4e | 257 | 209 | 5.0 | 7.9 | 11 | 36 |

TABLE 2 NOVEMBER 1986

TABLE 2(a) Record of numbers of soil dwelling invertebrates collected in pitfall traps.

| PLOT | COL. | ARAN. | CHIL. | DIPL. | ISOP. | ORTH. | OTHERS |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 4 | - | - | - | 11 | 5 Diptera/20 Hymenoptera<br>1 Lepidoptera/1 Hemiptera |
| 2a | 4 | 10 | - | 2 | 2 | 4 | 11 Diptera/2 Hymenoptera<br>1 Oligochaeta |
| 2cd | 5 | 14 | - | 13 | 2 | 3 | 6 Diptera/9 Hemiptera<br>2 Lepidoptera L.<br>15 Oligochaeta |
| 2e | 2 | 3 | - | 11 | 1 | 2 | 8 Diptera/1 Hemiptera<br>2 Hymenoptera/1 Lepidoptera L.<br>1 Mollusca/4 Oligochaeta |
| 3a | 5 | 7 | - | 2 | 1 | 7 | 4 Diptera/11 Hemiptera<br>20 Hymenoptera |
| 3cd | 5 | 3 | - | 1 | 4 | - | 3 Diptera/4 Hemiptera/5 Mollusca<br>2 Hymenoptera/1 Lepidoptera<br>8 Oligochaeta |
| 3e | 7 | 8 | - | 6 | 1 | 6 | 3 Diptera/3 Hymenoptera/3 Mollusca<br>4 Hemiptera/1 Oligochaeta |
| 4a | 1 | 9 | - | 2 | 1 | 8 | 8 Diptera/1 Lepidoptera/2 Mollusca<br>5 Hymenoptera/13 Hemiptera<br>12 Oligochaeta |
| 4cd | 8 | 13 | - | 5 | 7 | 3 | 11 Diptera/8 Mollusca<br>8 Hemiptera/2 Lepidoptera L.<br>13 Oligochaeta |
| 4e | 4 | 10 | - | 5 | - | 1 | 10 Diptera/16 Hemiptera<br>5 Hymenoptera/6 Mollusca<br>19 Oligochaeta |

TABLE 2(b) Metal concentrations in major groups of invertebrate fauna, four pooled samples per plot (ug/g, dry weight). NOVEMBER 1986

CARNIVOROUS SPECIES

(1) Predatory COLEOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | | | Insufficient sample size | | | |
| 2a | 236 | 19 | <5.4 | 4.4 | 6.0 | 25 |
| 2cd | | | Insufficient sample size | | | |
| 2e | 113 | 17 | 1.9 | 1.1 | 1.1 | 11 |
| 3a | | | Insufficient sample size | | | |
| 3cd | | | Insufficient sample size | | | |
| 3e | | | Insufficient sample size | | | |
| 4a | | | Insufficient sample size | | | |
| 4cd | 113 | 16 | <2.6 | 0.89 | 6.0 | 15 |
| 4e | | | Insufficient sample size | | | |

(2) ARANEIDA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | | | Insufficient sample size | | | |
| 2a | 261 | 67 | 4.2 | 4.3 | 7.6 | 10 |
| 2cd | 344 | 103 | 1.4 | 9.4 | 2.7 | 3.5 |
| 2e | 217 | 53 | <4.6 | 5.6 | 11 | <16 |
| 3a | 217 | 96 | <0.89 | 5.7 | 3.0 | <3.2 |
| 3cd | 160 | 35 | <2.6 | 1.4 | 11 | 9.6 |
| 3e | 238 | 85 | <2.9 | 5.3 | 10 | 15 |
| 4a | 297 | 168 | 2.1 | 8.0 | 8.4 | 19 |
| 4cd | 422 | 233 | 4.0 | 11 | 4.6 | 11 |
| 4e | 209 | 168 | <0.70 | 6.6 | 1.8 | <2.5 |

TABLE 2(b) contd....

HERBIVOROUS SPECIES

(2) ORTHOPTERA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | | | Insufficient sample size | | | |
| 2a | 257 | 40 | 0.86 | 2.9 | 3.0 | 8.5 |
| 2cd | 140 | 18 | 2.9 | 0.83 | 2.7 | <3.5 |
| 2e | | | Insufficient sample size | | | |
| 3a | 219 | 55 | 1.3 | 2.6 | 13 | 9.1 |
| 3cd | | | Insufficient sample size | | | |
| 3e | 181 | 31 | 3.3 | 1.9 | 9.8 | 25 |
| 4a | 276 | 52 | 2.5 | 4.1 | 5.7 | 16 |
| 4cd | 152 | 43 | 1.1 | 0.91 | 1.0 | 3.4 |
| 4e | | | Insufficient sample size | | | |

TABLE 2(b) contd...

DETRITIVOROUS SPECIES

(1) DIPLOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | Insufficient sample size | | | | | |
| 2a | 203 | 61 | <1.5 | 0.78 | 4.2 | <5.3 |
| 2cd | 239 | 110 | 1.1 | 0.94 | 2.3 | 2.3 |
| 2e | 236 | 127 | 0.89 | 0.69 | 2.7 | 4.3 |
| 3a | 192 | 111 | <0.88 | 0.48 | 3.2 | <3.1 |
| 3cd | 304 | 81 | 2.4 | 2.6 | 5.5 | <7.6 |
| 3e | 245 | 95 | 2.8 | 1.3 | 3.8 | 6.7 |
| 4a | Insufficient sample size | | | | | |
| 4cd | 505 | 141 | 7.0 | 4.4 | 12 | 16 |
| 4e | 460 | 89 | 1.7 | 3.2 | 3.6 | <5.8 |

(2) ISOPODA

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 1 | Insufficient sample size | | | | | |
| 2a | 382 | 187 | <7.9 | 4.6 | 20 | <28 |
| 2cd | Insufficient sample size | | | | | |
| 2e | Insufficient sample size | | | | | |
| 3a | Insufficient sample size | | | | | |
| 3cd | 419 | 130 | <1.6 | 3.4 | 7.5 | 10 |
| 3e | Insufficient sample size | | | | | |
| 4a | Insufficient sample size | | | | | |
| 4cd | 409 | 173 | 2.0 | 4.9 | 9.3 | 18 |
| 4e | 552 | 151 | 3.5 | 7.5 | 7.9 | 18 |

TABLE 3 Native earthworms MAY/NOVEMBER 1986

Metal concentrations were not corrected for the presence of soil within the earthworm gut.

Native earthworms collected in the pitfall traps at Ottawa MAY 1986

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 3cd | 1,811 | 122 | 22 | 40 | 49 | 146 |
| 3e | 1,710 | 70 | 9.3 | 38 | 15 | 50 |
| 4e | 694 | 72 | 16 | 10 | 52 | 173 |

Native earthworms collected in the pitfall traps at Ottawa NOVEMBER 1986

| PLOT | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| 2cd | 359 | 47 | 5.6 | 5.5 | 20 | 58 |
| 2e | 466 | 50 | 7.1 | 4.8 | 23 | 66 |
| 4a | 879 | 54 | 12 | 12 | 44 | 145 |
| 4cd | 969 | 64 | 14 | 11 | 41 | 131 |
| 4e | 794 | 50 | 14 | 9.6 | 50 | 157 |

APPENDIX E:

## Comparison of Metal Concentrations Within the Same Species and Between Different Genus of the Same Order.

Within an ecosystem some organisms accumulate metals to a greater extent than others and are referred to as target organisms (Martin and Coughtrey, 1982). Target organisms have a potential role for indicating the bioavailability of contaminants in the ecosystem. However, variation in metal concentrations between individuals of the same species and between different genus of the same Order influences their value as bioindicators. In order to assess this variation, two more detailed studies were carried out at Times Beach CDF: the first to assess variation in metal concentrations measured in individuals of the same species (the earthworms *Lumbricus rubellus*), and the second to compare metal concentrations between different genera of the same taxonomic Order (four genera of woodlice: Order Isopoda).

### Intra-specific variation.

Variations in metal concentrations between individual earthworms of the same species were assessed by comparing *L. rubellus* collected from two different vegetation zones (A and B) as defined by Wilhelm in 1985 (Stafford et al., 1987). Earthworms were collected using the formaldehyde vermifuge and held at 100% humidity for 48 hours for evacuation of soil in the gut before analysis. Ten earthworms were collected from a plot in zone A and six from a plot in zone B. Dried, whole, individual earthworms were weighed and metal concentrations measured (Stafford et al., 1987). Oven dry body weights and heavy metal concentrations of individual earthworms from each sampling plot were recorded (Table 1a). Means and standard deviations of the means for each element are also given.

Increase in concentrations of certain elements in earthworms has been associated with increase in the period of exposure to those elements e.g. Cd (Wade et al. 1982) and Cu, when present at high concentrations (Curry and Cotton, 1980). If increasing age were taken as indicative of increase in the period of exposure; adult, clitellate earthworms may be expected to have higher concentrations compared to immature (non-clitellate) specimens and assuming that body weight increases with age, some correlation between body weight and age may also be expected. Clitellate specimens did not have consistently higher heavy metal concentrations compared to non-clitellate specimens (Table 1a) and in most cases there was a poor correlation between body weight and heavy metal concentration (Table 1b).

Concentrations of the elements Fe, Al and/or Ti have been used in plant and animal studies of metal uptake to indicate whether or not soil is present in the samples (McGrath et al. 1982, Cherney and Robinson 1983, Cherney et al. 1983). High concentrations of these elements are known to be present in soils but not in plant and animal tissues. Results in Table 1a indicate that higher concentrations of these elements were observed in earthworms which also contained higher levels of the elements Cu, Cr, Ni and Pb, while lower levels of Fe, Al and Ti were measured in specimens containing lower levels of Cu, Cr, Ni and Pb. Conversely, Cd, which is known to accumulate within the earthworm tissue to levels exceeding those of the surrounding soil (see review by Beyer 1981) was measured in lowest concentrations in earthworms which had greatest concentrations of Fe, Al and Ti and vice versa (Table 1a). This pattern may be an indication that dredged material was present in the samples as a result of incomplete clearance of the gut by some of the earthworms. Correlation coefficients calculated between earthworm Fe, Al and Ti concentrations and heavy metal concentrations (Table 1b) indicated a close relationship between these elements and heavy metal concentrations. For all elements except Zn, high correlation coefficients were recorded between worm metal concentrations and concentrations of Ti, Fe and Al. These results suggest that the variation in metal concentrations between individual earthworms of the same species could be attributed to the presence of soil within the earthworm's gut. Correction to eliminate the effect of soil in the gut, using the method of Stafford and McGrath (1986) is likely to reduce this variation between individuals. It would be necessary to have information on the metal concentrations of the substrate/litter ingested by the earthworms to provide further evidence that the variations in metal concentrations measured in earthworms in this study were associated with substrate remaining within the earthworm gut.

Table 1a

Variation in Metal Concentration Between Individual *L. rubellus*.

| Sample | Oven dry body wt. | Ca | Ti | Fe | Al | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A 1* | 121.2 | 8159 | 33 | 7452 | 2121 | 1772 | 31 | 5.5 | 18 | 17 | 39 |
| A 2* | 112.5 | 3887 | 6.7 | 1295 | 239 | 1559 | 14 | <0.76 | 61 | 4.5 | 9.8 |
| A 3* | 104.1 | 3855 | 7.0 | 1245 | 326 | 1372 | 18 | 1.6 | 75 | 4.5 | 12 |
| A 4 | 102.3 | 5527 | 22 | 6725 | 1454 | 1789 | 24 | 5.4 | 69 | 19 | 33 |
| A 5 | 96.4 | 7136 | 20 | 5184 | 1199 | 1675 | 24 | 4.3 | 76 | 13 | 26 |
| A 6 | 84.4 | 4548 | 8.6 | 1683 | 304 | 1667 | 17 | 2.0 | 60 | 16 | 13 |
| A 7 | 127.9 | 5768 | 17 | 4347 | 972 | 1365 | 22 | 3.5 | 35 | 11 | 27 |
| A 8 | 69.3 | 5874 | 13 | 2337 | 397 | 1727 | 18 | 1.5 | 59 | 6.1 | 14 |
| A 9 | 96.6 | 6148 | 28 | 7587 | 1689 | 1379 | 25 | 3.4 | 26 | 15 | 38 |
| A 10 | 87.9 | 6041 | 28 | 7469 | 1209 | 1392 | 25 | 7.8 | 31 | 17 | 30 |
| Mean | 100.3 | 5694 | 18 | 4532 | 991 | 1570 | 22 | 3.6 | 51 | 12 | 24 |
| sd | 17.3 | 1354 | 10 | 2707 | 658 | 177 | 5.0 | 2.2 | 21 | 5.5 | 11 |
| B 1 | 72.1 | 5227 | 11 | 1446 | 396 | 1361 | 19 | <1.0 | 69 | 7.4 | 11 |
| B 2 | 133.5 | 4964 | 30 | 5439 | 1339 | 1499 | 37 | 4.2 | 43 | 12 | 20 |
| B 3 | 79.6 | 4916 | 19 | 2760 | 734 | 1486 | 21 | 2.1 | 80 | 8.1 | 18 |
| B 4 | 77.5 | 7637 | 17 | 2390 | 623 | 2265 | 21 | 1.6 | 102 | 8.9 | 23 |
| B 5 | 96.0 | 4582 | 11 | 1923 | 488 | 2629 | 21 | 1.6 | 159 | 5.2 | 18 |
| B 6 | 87.9 | 4089 | 16 | 1776 | 338 | 1995 | 17 | 1.3 | 75 | 4.1 | 11 |
| Mean | 91.1 | 5236 | 17 | 2622 | 653 | 1873 | 23 | 2.0 | 88 | 7.6 | 17 |
| sd | 22.4 | 1240 | 7.0 | 1456 | 366 | 508 | 7.2 | 1.2 | 40 | 2.8 | 4.9 |

Oven dry body weight measured in mg.
* clitellate earthworms.
All metal concentrations expressed in ug/g, dry weight.
A and B indicate the zones from which earthworms were collected.
sd = standard deviation of the mean.

Table 1b

Correlation Coefficients for the Linear Relationship Between Body Weight of *L. rubellus* and Heavy Metal Concentration and Between Ti, Fe and Al Concentration*[1] and Heavy Metal Concentrations in the Earthworms.

| Variable | Zn | Cu | Element Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|
| Zone A | | | | | | |
| Ti | -0.367 | 0.865 | 0.941 | -0.618 | 0.760 | 0.474 |
| Fe | -0.332 | 0.965 | 0.995 | -0.507 | 0.830 | 0.538 |
| Al | -0.356 | 0.961 | 0.981 | -0.475 | 0.886 | 0.597 |
| Oven dry body wt. | -0.064 | 0.913 | 0.904 | -0.278 | 0.522 | 0.331 |
| Zone B | | | | | | |
| Ti | 0.076 | 0.947 | 0.832 | -0.717 | 0.744 | 0.961 |
| Fe | 0.031 | 0.904 | 0.865 | -0.631 | 0.790 | 0.971 |
| Al | 0.155 | 0.961 | 0.742 | -0.632 | 0.739 | 0.978 |
| Oven dry body wt. | -0.207 | 0.290 | 0.106 | -0.307 | 0.020 | 0.322 |

*[1] Used as an indication of the presence of soil in the sample.

Inter-generic variation

Variation in metal concentrations between genera of the same taxonomic order was assessed using woodlice (Isopoda) collected in pitfall traps in fall 1985. Four genera were identified: Oniscidae *Oniscus*; Porcellionidae *Porcellio*; Trichoniscidae *Trichoniscus* and Armadillidiidae *Armadillidium*. For each genus the number of individuals was recorded, their oven dry weight (mg) measured and the relative numbers and weight of each genus (expressed as a percentage of the total) calculated (Table 2a).

Table 2a

Numbers and Weights of Isopoda Collected in the Pitfall Traps.

| Plot | Genus | Number | (Rel.%) | Weight | (Rel.%) |
|---|---|---|---|---|---|
| A1 | O. *Oniscus* | 44 | (22.45) | 0.580 | (43.19) |
| | P. *Porcellio* | 98 | (50.00) | 0.674 | (50.19) |
| | T. *Trichoniscus* | 48 | (24.49) | 0.031 | ( 2.31) |
| | A. *Armadillidium* | 6 | ( 3.06) | 0.058 | ( 4.32) |
| A2 | O. *Oniscus* | 17 | (14.41) | 0.249 | (28.52) |
| | P. *Porcellio* | 72 | (61.02) | 0.561 | (64.26) |
| | T. *Trichoniscus* | 16 | (13.56) | 0.026 | ( 2.98) |
| | A. *Armadillidium* | 13 | (11.01) | 0.037 | ( 4.24) |
| A3 | O. *Oniscus* | 3 | ( 2.94) | 0.092 | (13.65) |
| | P. *Porcellio* | 67 | (65.59) | 0.453 | (67.21) |
| | T. *Trichoniscus* | 6 | ( 5.88) | 0.003 | ( 0.45) |
| | A. *Armadillidium* | 26 | (25.49) | 0.126 | (18.69) |
| A4 | O. *Oniscus* | 10 | ( 6.21) | 0.130 | (18.44) |
| | P. *Porcellio* | 74 | (45.96) | 0.491 | (69.65) |
| | T. *Trichoniscus* | 65 | (40.37) | 0.029 | ( 4.11) |
| | A. *Armadillidium* | 12 | ( 7.45) | 0.055 | ( 7.80) |

Table 2a(contd.)

Numbers and Weights of Isopoda Collected in the Pitfall Traps.

| Plot | Genus | Number | (Rel.%) | Weight | (Rel.%) |
|---|---|---|---|---|---|
| B1 | O. Oniscus | 3 | ( 1.15) | 0.077 | (17.46) |
| | P. Porcellio | 46 | (17.62) | 0.276 | (62.58) |
| | T. Trichoniscus | 211 | (80.84) | 0.076 | (17.23) |
| | A. Armadillidium | 1 | ( 0.38) | 0.012 | ( 2.72) |
| B2 | O. Oniscus | 3 | ( 2.48) | 0.041 | (11.92) |
| | P. Porcellio | 36 | (29.75) | 0.267 | (77.62) |
| | T. Trichoniscus | 81 | (66.94) | 0.026 | ( 7.56) |
| | A. Armadillidium | 1 | ( 0.83) | 0.010 | ( 2.91) |
| B3 | O. Oniscus | 1 | ( 0.47) | 0.107 | (24.04) |
| | P. Porcellio | 40 | (18.96) | 0.261 | (58.65) |
| | T. Trichoniscus | 169 | (80.09) | 0.067 | (15.06) |
| | A. Armadillidium | 1 | ( 0.47) | 0.010 | ( 2.25) |
| B4 | O. Oniscus | 11 | (10.48) | 0.147 | (40.50) |
| | P. Porcellio | 36 | (34.29) | 0.198 | (54.55) |
| | T. Trichoniscus | 57 | (54.29) | 0.012 | ( 3.31) |
| | A. Armadillidium | 1 | ( 0.95) | 0.006 | ( 1.65) |
| B5 | O. Oniscus | 2 | ( 3.70) | 0.034 | (19.10) |
| | P. Porcellio | 23 | (42.59) | 0.139 | (78.09) |
| | T. Trichoniscus | 29 | (53.70) | 0.005 | ( 2.81) |
| | A. Armadillidium | 0 | | 0 | |
| C1 | O. Oniscus | 1 | ( 0.55) | 0.033 | ( 6.92) |
| | P. Porcellio | 40 | (22.10) | 0.348 | (72.96) |
| | T. Trichoniscus | 140 | (77.35) | 0.096 | (20.13) |
| | A. Armadillidium | 0 | | 0 | |
| C2 | O. Oniscus | 15 | ( 6.20) | 0.208 | (26.94) |
| | P. Porcellio | 80 | (33.06) | 0.515 | (66.71) |
| | T. Trichoniscus | 147 | (60.74) | 0.049 | ( 6.35) |
| | A. Armadillidium | 0 | | 0 | |
| C3 | O. Oniscus | 1 | ( 0.33) | 0.027 | ( 5.73) |
| | P. Porcellio | 25 | ( 8.31) | 0.342 | (72.61) |
| | T. Trichoniscus | 274 | (91.03) | 0.090 | (19.11) |
| | A. Armadillidium | 1 | ( 0.33) | 0.012 | ( 2.55) |
| C4 | O. Oniscus | 0 | | 0 | |
| | P. Porcellio | 27 | (19.01) | 0.264 | (79.52) |
| | T. Trichoniscus | 115 | (80.99) | 0.068 | (20.48) |
| | A. Armadillidium | 0 | | 0 | |

Where sufficient biomass was available, each genus from each plot was analysed (Stafford et al., 1987) and the metal concentrations, in ug/g, dry weight, are given in Table 2b.

Table 2b
Inter-Generic Differences in Metal Concentrations Between Isopoda Collected in Pitfall Traps.
Mean concentrations for four traps per plot in ug/g, dry weight.

| Plot | Genus | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|---|
| | | | | Element | | | |
| A1 | Oniscus | 133 | 258 | 2.4 | 38 | 4.9 | 23 |
| | Porcellio | 394 | 405 | 2.4 | 12 | 7.0 | 14 |
| | Trichoniscus | 258 | 144 | 3.5 | 62 | 21 | 22 |
| | Armadillidium | 278 | 307 | 2.0 | 4.5 | 9.4 | 12 |
| A2 | Oniscus | 134 | 252 | 3.6 | 46 | 14 | 21 |
| | Porcellio | 367 | 331 | 3.7 | 11 | 11 | 19 |
| | Trichoniscus | 126 | 62 | 6.6 | 26 | 65 | 12 |
| | Armadillidium | 322 | 431 | 4.7 | 6.9 | 24 | 20 |
| A3 | Oniscus | 100 | 174 | 1.8 | 41 | 9.9 | 31 |
| | Porcellio | 441 | 300 | 2.4 | 11 | 6.8 | 12 |
| | Armadillidium | 330 | 316 | 2.9 | 5.7 | 10 | 15 |
| A4 | Oniscus | 139 | 227 | 1.6 | 52 | 10 | 16 |
| | Porcellio | 407 | 342 | 2.7 | 15 | 8.0 | 14 |
| | Trichoniscus | 371 | 166 | 10 | 79 | 44 | 52 |
| | Armadillidium | 315 | 427 | 2.7 | 7.2 | 12 | 15 |
| B1 | Oniscus | 154 | 102 | 2.3 | 22 | 13 | 11 |
| | Porcellio | 395 | 313 | 2.8 | 13 | 7.5 | 14 |
| | Trichoniscus | 676 | 107 | 11 | 63 | 45 | 57 |
| B2 | Oniscus | 97 | 143 | 2.0 | 28 | 16 | 12 |
| | Porcellio | 315 | 212 | 2.7 | 13 | 6.8 | 12 |
| | Trichoniscus | 348 | 145 | 12 | 98 | 50 | 60 |
| B3 | Oniscus | 99 | 165 | 2.7 | 30 | 6.2 | 28 |
| | Porcellio | 343 | 242 | 2.8 | 12 | 4.8 | 12 |
| | Trichoniscus | 342 | 102 | 7.7 | 79 | 29 | 40 |
| B4 | Oniscus | 117 | 211 | 1.6 | 45 | 8.8 | 12 |
| | Porcellio | 422 | 302 | 2.4 | 17 | 13 | 12 |
| B5 | Oniscus | 143 | 122 | 14 | 46 | 9.9 | 11 |
| | Porcellio | 394 | 246 | 2.1 | 13 | 5.5 | 12 |

Table 2b(contd.)

Inter-Generic Differences in Metal Concentrations Between Isopoda Collected in Pitfall Traps.

| Plot | Genus | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|---|
| | | Element | | | | | |
| C1 | *Oniscus* | 120 | 169 | <2.8 | 40 | 22 | <9.6 |
| | *Porcellio* | 303 | 240 | 1.9 | 9.7 | 4.2 | 8.5 |
| | *Trichoniscus* | 189 | 85 | 3.3 | 47 | 11 | 16 |
| C2 | *Oniscus* | 133 | 169 | 1.7 | 33 | 5.3 | 11 |
| | *Porcellio* | 397 | 312 | 2.5 | 12 | 5.9 | 11 |
| | *Trichoniscus* | 273 | 120 | 3.8 | 62 | 24 | 21 |
| C3 | *Oniscus* | 158 | 185 | <2.7 | 37 | 23 | 15 |
| | *Porcellio* | 313 | 249 | 3.1 | 9.9 | 9.2 | 16 |
| | *Trichoniscus* | 225 | 92 | 6.3 | 59 | 25 | 35 |
| C4 | *Porcellio* | 285 | 151 | 1.4 | 10 | 5.3 | 7.9 |
| | *Trichoniscus* | 229 | 76 | 2.4 | 70 | 13 | 13 |

All concentrations expressed as ug/g, dry weight.

Differences in metal concentrations between genera of Isopoda were clearly evident from Table 2b. Mean metal concentrations for each taxonomic group were compared statistically in Table 2c.

Table 2c

Comparisons Between Metal Concentrations of Isopoda of Different Genera

Mean values expressed as ug/g, dry weight.

| Vegetation zone | Species | Zn | Cu | Ni | Cd | Cr | Pb |
|---|---|---|---|---|---|---|---|
| | | Element | | | | | |
| Zone A | *Armadillidium* | $311^{b*}$ | $370^{a*}$ | $3.1^{b}$ | $6.1^{c*}$ | $14^{b}$ | $16^{a*}$ |
| | *Oniscus* | $127^{c*}$ | $228^{b*}$ | $2.4^{b}$ | $44^{a*}$ | $20^{b}$ | $23^{a*}$ |
| | *Porcellio* | $402^{a*}$ | $345^{a*}$ | $2.8^{b}$ | $12^{b*}$ | $8.2^{b}$ | $15^{a*}$ |
| | *Trichoniscus* | $252^{bc*}$ | $124^{b*}$ | $6.7^{a}$ | $56^{a*}$ | $43^{a}$ | $29^{a*}$ |
| Zone B | *Armadillidium* | s | s | s | s | s | s |
| | *Oniscus* | $122^{b}$ | $149^{b}$ | $4.5^{b}$ | $33^{b}$ | $11^{b}$ | $15^{b}$ |
| | *Porcellio* | $374^{a}$ | $263^{a}$ | $2.6^{b}$ | $14^{c}$ | $7.5^{b}$ | $12^{b}$ |
| | *Trichoniscus* | $455^{a}$ | $118^{b}$ | $10^{a}$ | $76^{a}$ | $41^{a}$ | $52^{a}$ |
| Zone C | *Armadillidium* | s | s | s | s | s | s |
| | *Oniscus* | $137^{c}$ | $169^{b}$ | $1.5^{b}$ | $37^{b}$ | $17^{ab}$ | $12^{ab}$ |
| | *Porcellio* | $325^{a}$ | $267^{a}$ | $2.2^{ab}$ | $10^{c}$ | $6^{b}$ | $11^{b}$ |
| | *Trichoniscus* | $229^{b}$ | $93^{c}$ | $4.0^{a}$ | $60^{a}$ | $18^{a}$ | $21^{a}$ |

a,b,c - means values in a column within each zone followed by the same letter are not significantly different at $p < 0.05$.

* = Non-parametric statistical comparison of the means was employed.

s = insufficient sample size for analysis.

In terms of absolute metal concentrations, highest concentrations of Cd were present in the Trichoniscus followed by the Oniscus, and both of these groups had higher concentrations compared with the Porcellio and the Armadillidium. Conversely, Cu concentrations were highest in Porcellio and Armadillidium compared with Oniscus and Trichoniscus. The Trichoniscus generally contained higher concentrations of Ni, Cr and Pb compared with the other three genera, and the Oniscus generally contained lower concentrations of Zn compared with the other genera. However, when the contribution of each genus to the total biomass of Isopoda collected in the pitfall trap is also taken into consideration, a different picture emerges (Table 2a). The Trichoniscus, usually the most abundant genus in the traps, had the smallest weight per individual and their contribution to the total biomass was also generally small. Conversely the Oniscus, while present in small numbers, had a greater weight per individual and made up a greater proportion of the total biomass of Isopoda collected in the traps (Table 2a).

Thus, both metal concentration as well as relative biomass are factors which must be taken into consideration when metal concentrations of taxonomic groups are used as target organisms to indicate the nature and degree of contaminant mobility at a contaminated dredged material disposal facility.

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